AFRL-SA-WP-SR-2013-0003

BASE-LEVEL GUIDE FOR ELECTROMAGNETIC FREQUENCY RADIATION

Matthew W. Uelen
Battelle Memorial Institute

Bret Z. Rogers
U.S. Air Force School of Aerospace Medicine, Occupational and Environmental Health Dept, Consultative Services Division

December 2012

Air Force Research Laboratory
711th Human Performance Wing
USAF School of Aerospace Medicine
Occupational & Environmental Health Dept
Consultative Services Division
2510 Fifth St.
Wright-Patterson AFB, OH 45433-7913

NOTICE AND SIGNATURE PAGE

AFRL-SA-WP-SR-2013-0003 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

//SIGNATURE//	//SIGNATURE//
David M. Sonntag, Lt Col, USAF, BSC Chief, Consultative Services Division	Mark E. Smallwood, Col, USAF, BSC Chair, Occupational & Envinronmental Health Dept

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 31 Dec 2012	**2. REPORT TYPE** Special Report	**3. DATES COVERED *(From – To)*** Dec 2011 – Dec 2012
4. TITLE AND SUBTITLE Base-Level Guide for Electromagnetic Frequency Radiation		**5a. CONTRACT NUMBER**
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Matthew W. Uelen, Battelle Memorial Institute Bret Z. Rogers, DAF		**5d. PROJECT NUMBER**
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) USAF School of Aerospace Medicine Occupational & Environmental Health Dept Consultative Services Division (USAFSAM/OEC) 2510 Fifth St. Wright-Patterson AFB, OH 45433-7913		**8. PERFORMING ORGANIZATION REPORT NUMBER** AFRL-SA-WP-SR-2013-0003
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)		**10. SPONSORING/MONITOR'S ACRONYM(S)**
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Distribution A: Approved for public release; distribution is unlimited. Case Number: 88ABW-2013-1620, 2 Apr 2013

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This guidance document provides basic information on processes performed in the United States Air Force regarding electromagnetic frequency (EMF) radiation. This base-level guide includes potential hazards of EMF emitters, recommends engineering and administrative controls, and recommends practices for assessing potential exposure to EMF emitters. Supersedes USAFSAM REPORT 89-023RC0111ORA.

15. SUBJECT TERMS

Occupational exposure, electromagnetic field, radio frequency radiation

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Col Mark E. Smallwood
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	SAR	113	**19b. TELEPHONE NUMBER *(include area code)***

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

TABLE OF CONTENTS

Chapters

List of Figures

List of Tables

List of Equations

1. Introduction

a. The purpose of this Guide is to assist the base level aerospace medical team (i.e., Bioenvironmental Engineering (BE), Public Health (PH) and Occupational Medicine Consultants, etc). in managing their Electro Magnetic Frequency (EMF) radiation protection programs, specifically Radio Frequency (RF) Radiation. This guide is used in conjunction with Air Force Occupational Safety and Health (AFOSH) Standard 48-9. Part of the EMF spectrum is also known as RF Radiation and the two terms are frequently used and refer to the same part of the energy spectrum. EMF also includes portions of the spectrum known as Extremely Low Frequency (ELF) and the Microwave radiation regions. Both "EMF" and "RF" are correct terms when describing the frequency range of 3 kHz – 300GHz, however EMF is the term that is recommended.

b. This is the first revision of the original EMF BE Guide and many sections were rewritten. Example emitters were updated to reflect today's technology. Permissible Exposure Limits (PELs) have been replaced by Maximum Permissible Exposure (MPE) limits. Based upon IEEE changes, their range and breadth of coverage has been refined and expanded. While monitoring techniques have remained mostly the same, new options are becoming available and are noted. The survey and sampling documentation process has changed with the advent of Defense Occupational Environmental and Halth Readiness System (DOEHRS). This guide was expanded to cover the increased EMF training that is required in the latest AFOSH Std 48-9. The incident/injury investigation requirements were vastly revised.

c. Appendix B of this report contains updated emitter information based on reports compiled by USAFSAM. This appendix provides access to a partial list of inventoried emitters. This appendix also provides some example emitters where actual exposure and emitter nomenclature is utilized.

d. This standard excludes broadband light hazards i.e., UV, visible light, white light/broadband, and laser optical radiation frequencies standards and reporting that are covered by AFI 48-139.

e. This guide and AFOSH 48-9 do not cover electromagnetic compatibility testing or the assessment of hazards associated with electro-explosive devices (EEDs) and fuel handling operations. All questions and concerns must be referred to the 85th EIS/SCYM, 670 Maltby Hall Drive, Suite 234, Keesler AFB MS 39534-2633, DSN 597-3926 or (228) 377-3926. Air Force Safety (AF/SE) establishes and implements all policy and inspection standards for safety programs associated with the non-biological hazards of EMF-producing systems and equipment, e.g., hazard of electromagnetic radiation to ordnance (HERO), and hazard of electromagnetic radiation to fuel (HERF).

2. EMF in the Air Force

a. The "Big Picture"

(1) The application of new EMF technologies has been flourishing since the millennium. Motivations for this boom include the implementation of new wireless services, the utilization of

new materials in the realization of new and low cost EMF components, and the development of enhanced radars and sensors for an assortment of applications. The USAF is prominently positioned to be a leader in this field with its communication and sensor interests. To illustrate this point, devices that emit EMF have been an essential part of our "fly, fight, and win" mission. They allow us to predict the weather, "see and confuse" the enemy, stop our enemies, control our aircraft and weapons and communicate. Emitters are found in hospitals, in R&D labs, on hilltops, on flight lines, in maintenance workplaces, on roofs, in kitchens, in offices, etc.

(2) For many Air Force personnel, some exposure to EMF is "just part of the job"; for others, exposures are very rare. It is true almost all routine exposures today are at very low levels, with power densities much less than 10 W/m^2 (watts per meter squared). But levels as high as 1,000 W/m^2 can be found in some areas. AFOSH Std 48-9 specifies occupational limits for EMF above which workers may not be exposed.

(3) EMF is often overlooked when compared to physical hazards. Antennas of varying size and shape hide behind radomes with emissions normally undetectable to the senses. Large antenna structures are often relatively harmless, while smaller antennas may create significant hazards. Many factors can alter the power density produced by an emitter. It is often difficult to accurately predict the location of a hazard unless the surveyor understands the terrain surrounding the site, operational use of the device, accessibility of personnel, and the operational parameters of the system.

(4) Even with the complexities of EMF, the possibility of exposure to excessive levels of EMF need not be a major concern. In most cases, the means of adequate protection are quite simple. This is where the BE and aerospace medical team enter the picture.

b. Bioenvironmental Engineering (BE) Role

(1) The installation bioenvironmental engineer and technicians are charged with implementation of an EMF protection program as specified in AFOSH 48-9; basically a safety and health effort that identifies and controls all areas where the potential for exposures to EMF above the MPE values exist. The main constituents of the program are straight forward:

(a) Maintain an inventory of emitters.

(b) Periodically re-evaluate emitters during site inspection surveys.

(c) Evaluate new emitters as they are brought to the installation.

(d) Make recommendations on control measures based on emitter characteristics and survey data.

(e) Assess/monitor potentially exposed personnel and areas and perform EMF calculations as necessary.

(2) Don't think of EMF any differently than any other occupational industrial hygiene hazard. It's still a BE's role to anticipate, recognize, evaluate and control EMF workplace exposures that could cause workers' injury or illness.

(3) EMF Awareness Training is an integral part of the safety envelope. While the principle tasking rests with the unit commanders, EMF hazard education should be a joint effort between, the 711th HPW (USAFSAM/OE), base AF/SE, base BE and the EMF operation/user supervisors. While the effort may be time consuming, the payoff is a successful and effective EMF protection program. See page 43 for more details on training requirements.

3. Understanding Radio Frequency Radiation

a. The EMF Spectrum

(1) General. The known spectrum of EMF waves covers a wide range of frequencies including AM, FM, TV signals, microwave, as well as x-rays, gamma rays, and visible light. Figure 1 shows the EMF spectrum.

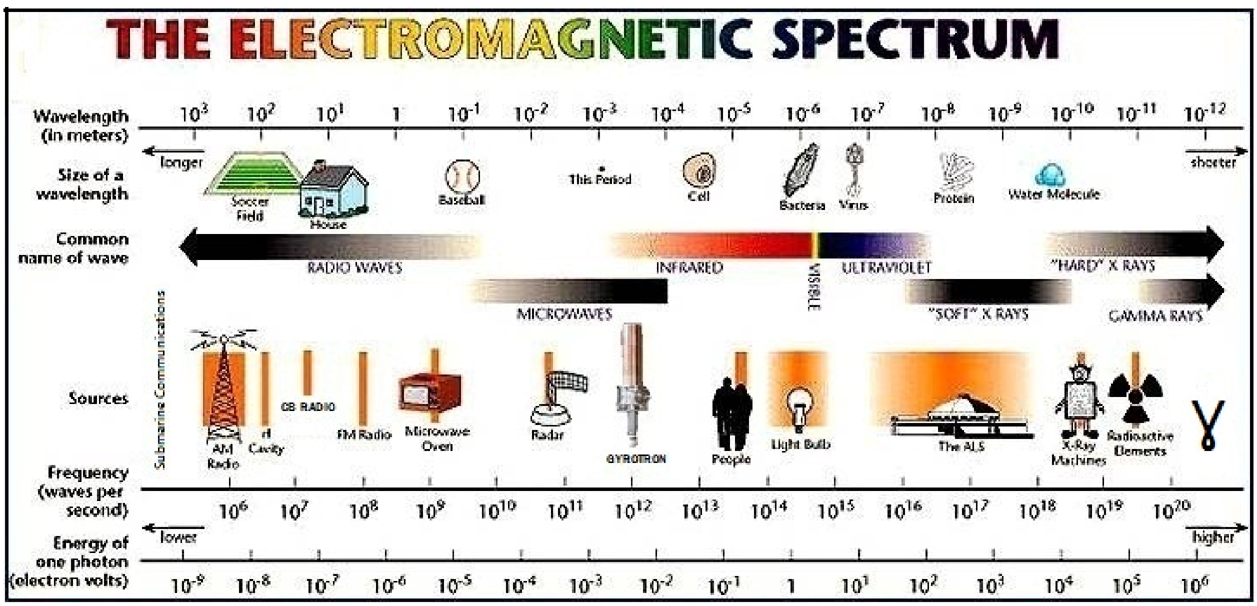


Figure 1. The Electromagnetic Spectrum

All types of EMF waves travel at the speed of light (3 x 10^8 meters(m) /second in free space). Wavelength and frequency are related by Equation 1:

$$\lambda = c/f$$

Equation 1. Wavelength-Frequency Calculation

Where λ is the wavelength in meters, f is the frequency in hertz (which is pulses per second), and c is the speed of light (3 x 10^8 meters/second). For example, if an EMF source emits at 100 megahertz (MHz 10^6 Hz); the wavelength of the emission would be 3 meters.

$$\lambda = 3 \text{ x } 10^8 \, \frac{\text{m}}{\text{s}} / 100 \text{ x } 10^6 \text{MHz} = 3 \text{ meters}$$

See Appendix H, Example 2, for another example of equation 1.

EMF is just the part of the Electromagnetic (EM) spectrum that extends in frequency from 3 kilohertz (kHz or 10^3 Hz) to 300 gigahertz (GHz or 10^9 Hz). Table 1 defines the radio frequency bands. Unlike x-ray and gamma radiation, EMF is non-ionizing radiation such that the energy of any photon is insufficient to dislodge orbital electrons and produce ion pairs. This important distinction is not well understood by many people who equate all types of "radiation." Biologically, the effects of ionizing and non-ionizing radiation are completely different.

Table 1a. Most Common Radio Frequency Bands (not to scale)

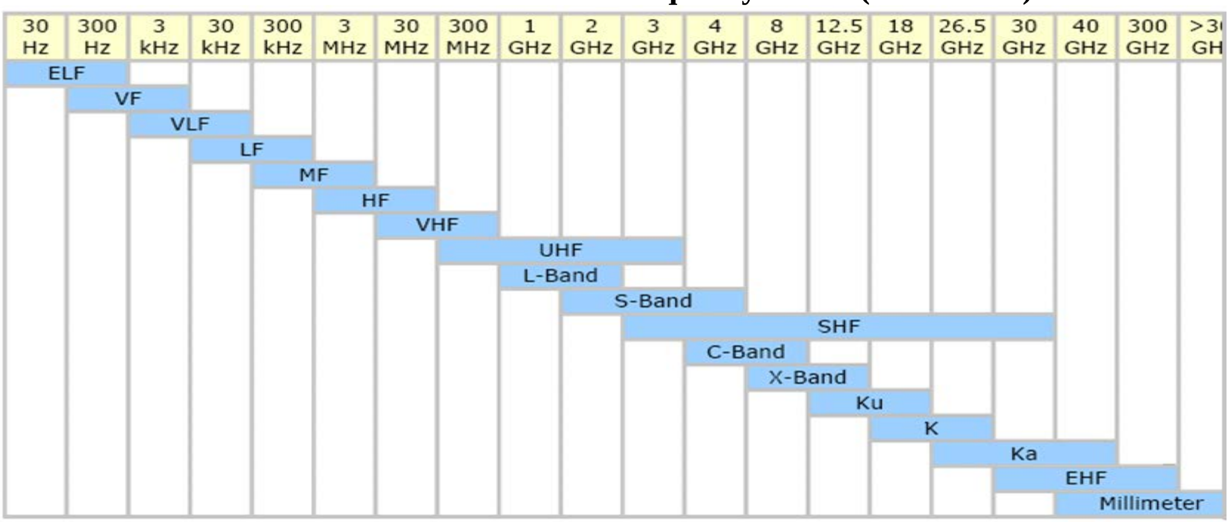


Table 1b. Major Radio Frequency Bandwidths

Major Bandwidths	Bandwidth Descriptions	Frequency
ELF	Extremely Low Frequencies	30 – 300 Hz
VF	Voice Frequencies	0.3 – 3 kHz
VLF	Very Low Frequencies	3 – 30 kHz
LF	Low Frequencies	30 – 300 kHz
MF	Medium Frequencies	0.3 – 3 MHz
HF	High Frequencies	3 – 30 MHz
VHF	Very High Frequencies	30 - 300 MHz
UHF	Ultra High Frequencies	0.3 – 3 GHz
SHF	Super High Frequencies	3 – 30 GHz
EHF	Extremely High Frequencies	30 – 300 GHz

(2) Electromagnetic Radiation Propagation: Electromagnetic energy propagates through space in the form of waves composed of mutually supporting electric ("E") and magnetic ("H")

fields. These two fields vary together in intensity, but their directions are at the right angles to each other in space, and both are at right angles to the direction of propagation. Figure 2 depicts this relationship.

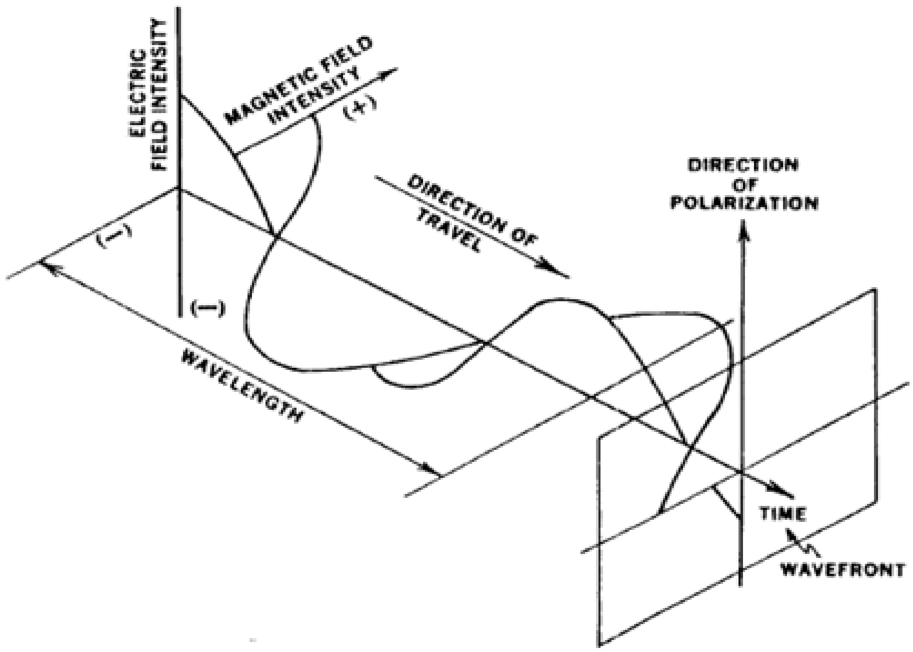


Figure 2. Electromagnetic Radiation Wave

(3)   More in-depth details about electromagnetic radiation can be found in the Radiofrequency Radiation Dosimetry Handbook, USAFSAM-TR-85-73 and AFOSH Std 48-9.

b.   Emitters

(1)   General: All EMF emitters have three basic components: a transmitter, a transmission line, and an antenna. Emitters often transmit and receive, but the amount of “received” energy is in the negative decibels, not hazardous and not the focus of this guide. Figure 3 illustrates the basic EMF emitter configuration.

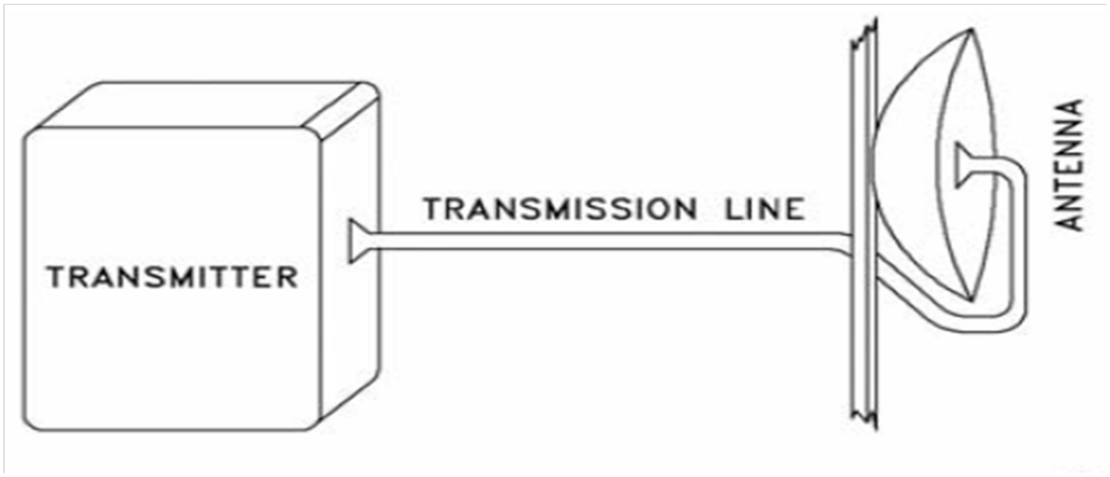


Figure 3. Basic EMF Emitter Components

(2) Categories by Application: EMF emitters have a broad array of uses. All of the emitters you encounter on your base should fit into one of these categories.

(a) Communications

1 Fixed: Radio communications between specified fixed points.   Examples: Military Affiliated Radio System (MARS), point-to-point microwave links

2 Airborne: Radio communications between land station and an aircraft ("ground-to-air" or "air-to-ground") or between aircraft ("air-to-air").

3 Land mobile: Radio communications between a base station and a mobile station or between land mobile stations. Examples: intrabase ("non-tactical") systems such as police, fire or hospital nets, tactical radios, "CB" radios, and cell phones. The use of cell phones has exponentially increased in the past decade. This has led to an increase in the number of base stations. These are often sited in public areas. However, the exposure to the public from these stations is low risk as they generally do not exceed the MPE. The systems usually operate on frequencies near 900 MHz or 1.8 GHz using either analogue or digital technology. Bluetooth devices intended for use in short-range personal area networks operate from 2.4 to 2.4835 GHz. Phones and Bluetooth devices are technically small, low power radio transmitters that are held in close proximity to the head when in use.

4 Wireless local area networks (WLAN (indoor and outdoor)): are very safe when properly installed and used. WLAN systems operate on extremely low power (less than that of a cell phone). It is important that only AF approved equipment be used. The placement of base station antennas (2.4 GHz) should be high on a wall or on the ceiling. Commercially procured telecommunications systems designed for public use (e.g. cellular phones, Wi-Fi networks) that are used in their manufactured condition do not require evaluations.

5 Space: Communications between land station or aircraft and spacecraft.

6 Broadcast: Radio communication intended for direct reception by the general public. Examples: AM and FM radio, digital and satellite television.

(b) Navigation

1 Fixed: Land based systems designed to provide navigational aid (distance and/or bearing) directly to indicators aboard aircraft or on the ground. Examples: VHF Omni-direction Radial (VOR), Tactical Air Navigation (TACAN), radio beacons, instrument landing systems (ILS).

2 Airborne: Systems aboard aircraft designed to provide navigational information from the aircraft point of reference. Examples: radar altimeters, Doppler radar, terrain following radar.

(c) Radar (RAdio Detection And Ranging)

1 Fixed: Land based systems designed to detect and indicate the position of weather disturbances, aircraft, spacecraft, etc. Radar systems normally use microwave frequencies and waveguides. Examples: search radar, tracking radar, height-finding radar.

2 Airborne: Aircraft systems designed to detect and indicate the position of obstructions, weather disturbances, other aircraft, etc. Examples: fire control radar, side looking radar, tracking radar, mapping radar.

Table 2 denotes the common letter designations for microwave radar bands as specified by the International Telecommunication Union. The designations are for Region II (North and South America.)

Table 2. Radar Band Designations

Band	Frequency (MHz)
P	225 – 390
L	390 – 1,550
S	1,550 – 5,200
C	3,900 – 6,200*
X	5,200 – 10,900*
K	10,900 – 36,000
Q	36,000 – 46,000
V	46,000 – 56,000
W	56,000 – 100,000

*There may be some overlap between adjacent bands.

(d) Electromagnetic Countermeasures (ECM): Land-based or airborne EMF systems designed to emit signals that disrupt the effective use of a portion of the EM spectrum. Examples: threat recognition systems, communications jammers, radar jammers. Table 3 denotes the common ECM band designations.

Table 3. ECM Band Designations

Band	Frequency (MHz)
A	0 – 250
B	250 – 500
C	500 – 1,000
D	1,000 – 2,000
E	2,000 – 3,000
F	3,000 – 4,000
G	4,000 – 6,000
H	6,000 – 8,000
I	8,000 – 10,000
J	10,000 – 20,000
K	20,000 – 40,000
L	40,000 – 60,000
M	60,000 – 100,000

(e) Industrial/Commercial: EMF systems designed to perform a heating function for industrial applications. Examples: EMF heat sealers (27.12 MHz,) induction heating ovens, dielectric heating ovens (915 and 2450 MHz,) microwave ovens (2.45 GHz) and high voltage power supplies that operate in the RF/microwave range. These systems are not true emitters in that the EMF fields are incidental byproducts.

(f) Medical: Systems that utilize the thermal effects of EMF energy for medical applications. Examples: diathermy (3-30 MHz,) cauterization/electrosurgery (100 kHz - 5 MHz) and interstitial microwave hyperthermia (300 MHz-300 GHz.)

(g) Directed Energy EMF Weapons: High and low power pulsed microwave devices that use low-frequency microwave radiation. The heart, lungs, and other vital organs are controlled by very low voltage electronic signals from the human brain. It should be possible to disrupt, potentially catastrophically, such signals from a distance using this technology. A few examples are listed below:

1 Active Denial System (ADS) is a deterrent system that works by firing a high-powered beam of electromagnetic radiation in the form of high-frequency millimeter waves at 95 GHz and with a wavelength of 3.2 mm. The beam can be focused up to 700 meters away, and is said to penetrate thick clothing. The energy beam heats the surface of the skin and causes pain. At 95 GHz, the frequency is much higher than the 2.45 GHz of a microwave oven. This frequency was chosen because it penetrates less than 1/64 of an inch (0.4 mm), which in most humans, except for eyelids and babies, avoids the second skin layer (the dermis) where critical structures such as nerve endings and blood vessels are found. Silent Guardian is a stripped-down model of ADS used commercially for crowd control.

2 Vigilant Eagle is an airport defense system that directs high-frequency microwaves towards any projectile that is fired at an aircraft. The system consists of a missile detecting and tracking subsystem (MDT), a command and control system, and a scanning array. The MDT is a fixed grid of passive infrared (IR) cameras. This command and control system determines the missile launch point. The scanning array emits microwave energy pulses to disrupt surface-to-air missile guidance systems.

3 Bofors High Power Microwave (HPM) Blackout is a high-powered microwave weapon system which is stated to be able to destroy, at a distance, a wide variety of commercial off-the-shelf (COTS) electronic equipment.

Air Force Instruction (AFI) 91-401, Directed Energy Weapons Safety implements the safety program requirements for use of directed energy weapons and gives safety responsibility to AF/SE. BE is responsible for evaluating (indirect) exposures to operating personnel of these systems.

c. Transmitters

(1) General: The transmitter is one of the basic elements of the EMF emitter. The primary function of the transmitter is to generate an EMF signal. Figure 4 depicts the basic transmitter configuration.

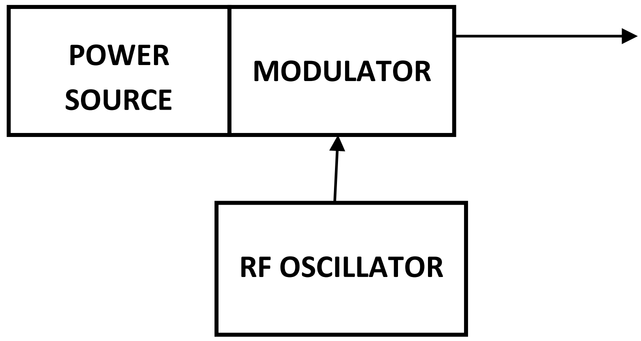


Figure 4. Basic Transmitter Configuration

(2) Transmitter Types: There is a vast array of different transmitters in the Air Force. Low power, hand-held or transportable transmitters can implement solid state amplifiers like common silicon transistors, diodes, or Field Effect Transistors. Power output from these devices is typically one to 10 watts. Other devices that require high power sources may contain magnetron oscillators, crossed-field amplifiers, klystrons, traveling-wave tube amplifiers, backward wave oscillators, gyrotron amplifiers, electron tubes, etc. These devices typically are found in high power radar and communications systems. On the other hand, high power radar can be powered by many low power transmitters. The PAVE PAWS phased-array radar uses 3,584 transistor modules that individually have a power output of only 440 watts.

(3) Transmitter Characteristics: Transmitter specifications can often be very complex. Often when the BE or one of their technicians attempt to acquire parameters from system operators, they are overwhelmed by a lot of complex and sometimes useless (from the BE's standpoint) information. It is your job to weed through this information and find the useful information. Concerning transmitters, the following parameters are needed:

(4) Power: The power rating of a transmitter is necessary to evaluate an EMF system. All emitters transmit either a continuous wave (CW) or a pulsed waveform. "Pulsed" simply means that the transmitter is not continuously energized. For systems that provide CW EMF transmissions, power is specified as average power. For pulsed systems, most commonly radar, transmitter power is expressed as a peak power (P_{peak}). The average power (P_{av}) of a pulses system can be calculated by multiplying the (P_{peak} by the duty factor (DF). The DF, also called duty cycle or duty ratio that accounts for the fraction of time the transmitter is "on" and is a product of pulse width (PW) and pulse repetition frequency (PRF). Equations 2 and 3 describe this relationship, while Figure 5 depicts a typical pulsed transmission. Example 1 of Appendix H provides examples of the uses of these two equations.

$$P_{av} = P_{peak} \times DF$$

Equation 2. Average Power Calculation

$$DF = PW \times PRF$$

Equation 3. Duty Factor Calculation

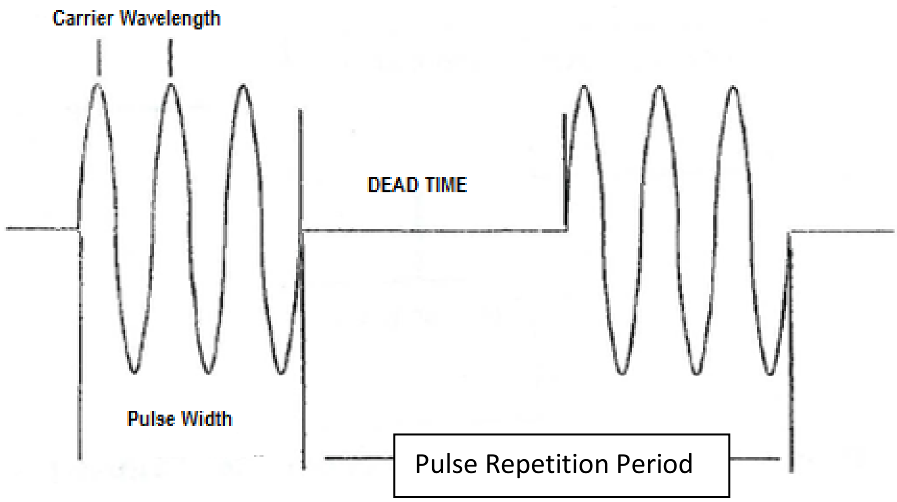


Figure 5. Typical Pulsed Transmission

Transmitter power ratings can be specified in many units. Usually they are specified in watts (W) or kilowatts (kW), but commonly, radio engineers use the unit of decibel meters (dBm): power output relative to 1 milliwatt (mW), i.e., 1 mW is equivalent to 0 dBm. For example, a transmitter with an output of 50 dBm has an equivalent output power of 100 W. Equations 4 and 5 describe this relationship.

$$P(\text{dBm}) = 10\log_{10} [P(\text{mW})] \quad \text{(i.e., calculator function } 10\log_{10} = \log \times 10)$$

Equation 4. Watts to Decibels Conversion

$$P(\text{mW}) = \log^{-1}[P(\text{dBm})/10] \quad \text{(i.e., } \log^{-1} = 10^{x} \text{ function on calculator)}$$

Equation 5. Decibels to Watts Conversion

(5) Frequency: The operating frequency of the transmitter is necessary to evaluate the EMF emitter. Most systems have their operating frequency specified in megahertz (MHz). Some systems operate at one intended discreet frequency, while others operate across a continuous range of frequencies or frequency bands. Confusing the operating frequency of the system with the pulse repetition frequency of a pulsed system or the bandwidth specification is a common error made by personnel evaluating an emitter. Both of these parameters will always be less than the system operating frequency. Determining the range of frequency operation is important for the evaluation of an emitter. For some emitters, especially HF, the MPE and antenna gain can vary drastically across the operating frequency range. Often it is necessary to evaluate and measure an emitter at several discreet frequencies.

(6) Modulation: Modulation is the process where certain characteristics of the EMF wave (also called the carrier wave) are varied in accordance with the message signal. Modulation can be divided into continuous modulation where the modulation signal is always present and pulse modulation where no signal is present between pulses.

(a) Continuous Modulation: Communications systems like AM and FM radio, TV, police and fire nets, and CB radios use this type of modulation. Although there are numerous forms of continuous modulation, we will examine a few of the more common ones.

(b) Amplitude Modulation (AM): In amplitude modulation, the carrier wave frequency remains unchanged while its amplitude is varied according to the modulating (message) signal. Three of the most common types of amplitude modulation are doubled sideband (DSB), conventional amplitude modulation, and signal sideband (SSB). Figures 6 and 7 depict a representative carrier and message signal respectively, while Figure 8 shows resulting conventional amplitude modulated output signal.

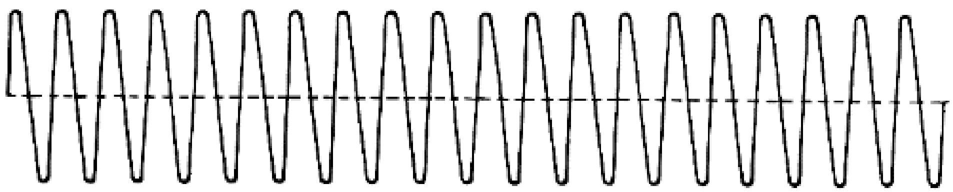


Figure 6. Representative Carrier Signal

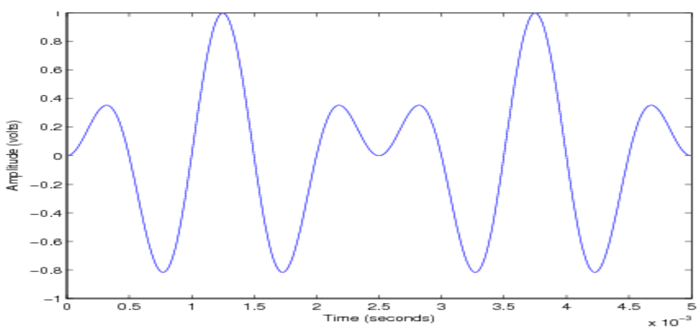


Figure 7. Representative Message Signal

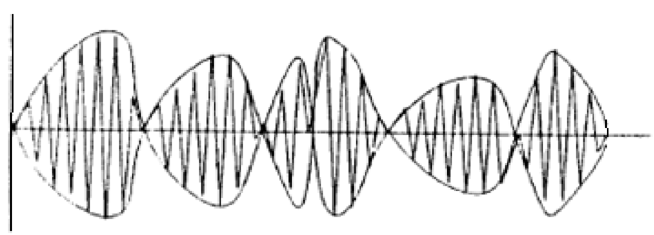


Figure 8. Conventional Amplitude Modulated Output Signal

(c) While performance characteristic differences between these types of amplitude modulation are important to the radio engineer, from a safety viewpoint, we are concerned with the difference between peak envelope power and the average power of a signal modulated by a voice or a tone (such as a telegraph transmission). Generally, SSB transmissions will have an average power approximately equal to 10 percent of the peak power.

(d) Additionally, it is common for amplitude modulated signals to have a suppressed carrier in the space of single and double sideband systems. For systems with suppressed carrier, there is zero output power during non-transmission times.

(e) A third factor that can influence the average power output of an emitter is keying. Some transmitters (such as hand-held radios are voice-keyed or manually-keyed) produce a power output only when they are keyed. Other emitters (such as satellite terminals or telemetry units) employ continuous power output. Generally, these emitters carry telegraphy or electronic control signals which require no receive time, or they receive on a different frequency than they transmit.

(f) Frequency Modulation (FM). In frequency modulation, the carrier wave amplitude remains unchanged while the carrier frequency varies in accordance with the message signal. Figure 9 depicts a representative FM signal.

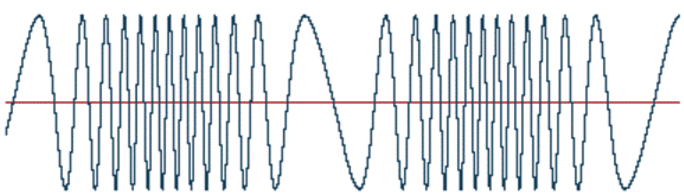


Figure 9. Frequency Modulated Signal

(g) Pulse Modulation: In pulse modulation, the unmodulated carrier is usually a series of regularly recurrent pulses. Information is conveyed by modulating some aspect of the pulse, e.g., amplitude or duration (pulse width). Figure 10 shows a pulse-amplitude modulated signal.

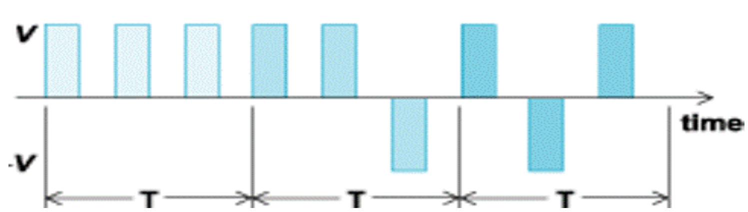


Figure 10. Pulse Modulated Signal

d. Transmission Lines

(1) General: As shown in Figure 3, the transmission line is a critical element in an EMF emitter, providing a link from the transmitter to the antenna.

(2) Types: There are two types of transmission lines; one conductor and two conductor. A one conductor transmission guide propagates EMF through a hollow tube called a waveguide. Waveguides can have many shapes: rectangular, circular, square, etc. Waveguides are used to transmit EMF at microwave frequencies. There are numerous types of two conductor transmission lines, the most common being single coaxial line and parallel wires. Two conductor lines are more commonly encountered in lower frequency systems (operating below 1 GHz).

(3) Losses: All waveguides and transmission lines have power losses. Power losses are mostly attributed to the production of heat in the conductor; however, a certain amount of energy can be leaked as EMF by the transmission line. Power losses are normally expressed in decibels. Equations 6 and 7 can be used to convert between decibel (dB) and absolute units.

(4) Transmission Line Antennas and their hazards: As noted above, transmission lines propagate EMF like an antenna. In close proximity of transmission lines, EMF hazards can exist. While these hazards are system unique and dependent on transmitted power, transmission line construction, etc., the phenomena are more common in HF and UHF systems.

(5) Leaky or broken waveguides can also propagate EMF like an antenna. There have been a number of overexposure investigations from leaky or broken waveguides. The size of a waveguide break is the most important factor in determining its ability to behave as an antenna. For example, if the largest dimension of the break is smaller than one-half the system wavelength, the break will not effectively emit EMF. On the other hand, if the break's greatest dimension is greater than on-half the system wavelength, the break could effectively emit EMF. Power densities from a waveguide break can be estimated using a horizontal dipole antenna model with zero gain.

e. Antennas

(1) General: The antenna is a basic component of any EMF system. The antenna is the connecting link between free space and the transmitter. Its design is largely dependent on the intended use of the system in question. In many systems used for navigation or direction-finding, the operational characteristics of the system are designed around the directive properties of the antenna. In other systems, the antenna may be used simply to radiate energy in all directions to provide broadcast coverage.

(2) Antenna Properties: Regardless of the systems application all antennas have basic properties that can be well defined: Antenna-gain, size, accessibility, and radiation pattern are of principle interest in evaluating radiation hazards.

(a) Gain

1 The gain or directivity of an antenna is the measure of its ability to concentrate its energy in a certain direction. Directivity is closely related to the radiation pattern of an antenna. To understand antenna gain, first, picture an isotropic emitter: a hypothetical

EMF source that radiates evenly in all directions from a point in space. Figure 11 shows an isotropic emitter.

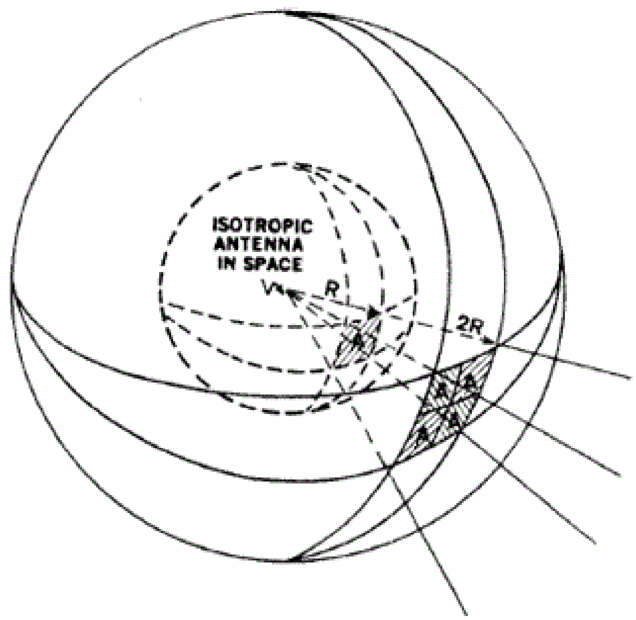


Figure 11. Isotropic Emitter

Next, imagine the addition of an antenna that emits the same total amount of energy, but redirects that energy into half as much area. The gain of this antenna is 2, because the energy in the direction of maximum radiation is doubled. Another antenna that uniformly directs the energy into a quarter of the area has a gain of 4, and so on. Gain is the ratio of the maximum radiation intensity in a given direction to the intensity produced by an imaginary isotropic emitter. Antenna power gain can be expressed as a unitless number (absolute gain, G_{abs}) or, more commonly in decibels (dB). The "I" term is often added to dB (dBi) when discussing the gain of the antenna with respect to that of an isotropic antenna. Equations 6 and 7 describe this relationship to convert these units. See Appendix H, Example 1, for an example of equation 7 in use.

$$\text{Gain (dBi)} = 10\log10[G_{abs}]$$

Equation 6. Gain Calculation

$$G_{abs} = \log\text{-}1[\text{Gain(dBi)}/10]$$

Equation 7. Gain (Absolute) Calculation

2 There are practical limits on antenna gain. The previously discussed isotropic emitter is purely hypothetical; in practice it is impossible to construct an isotropic emitter. As a

result, it is theoretically impossible for a radiating antenna to have a gain of 1 dBi or less. However, maintenance personnel may erroneously claim that the gain of an antenna is less than 1, often zero. Some common reasons for incorrect gain specifications are:

- The specified gain may include transmission line losses.

- Maintenance personnel may be confusing antenna gain (power density gain resulting from special concentration of energy, in dBi) with electronic gain (power gain created by electronic amplifiers, in dB).

- Ground reflectance can increase gain values if the redirected energy is "in-phase" with the direct energy (by as much as four times.)

- The emitter may be dummy loaded, in which case the antenna gain is undefined, but may be specified as zero. See Appendix I for more information on Dummy Loads.

(b) Antenna Regions: The field radiated from an antenna varies greatly in structure depending on the distance from the antenna. In this section, we will introduce three regions around an antenna: the far-field, the near-field, and the transition region. Knowledge of the three regions is necessary to predict radiation field power densities and determine limitations in making field measurements. Although these three regions exist around all types of antenna, we will use an aperture antenna as an example. Figures 12 a and b provide two-dimensional graphic representation of the three regions using an aperture antenna.

1 Far-Field (Fraunhofer Region): At large distances from the antenna, the propagated EMF field, as observed from any given point, takes on the appearance of a uniform plane wave. Under these conditions, the electric field and magnetic field are perpendicular to each other, and both are perpendicular to the direction of wave propagations as show in Figure 13.

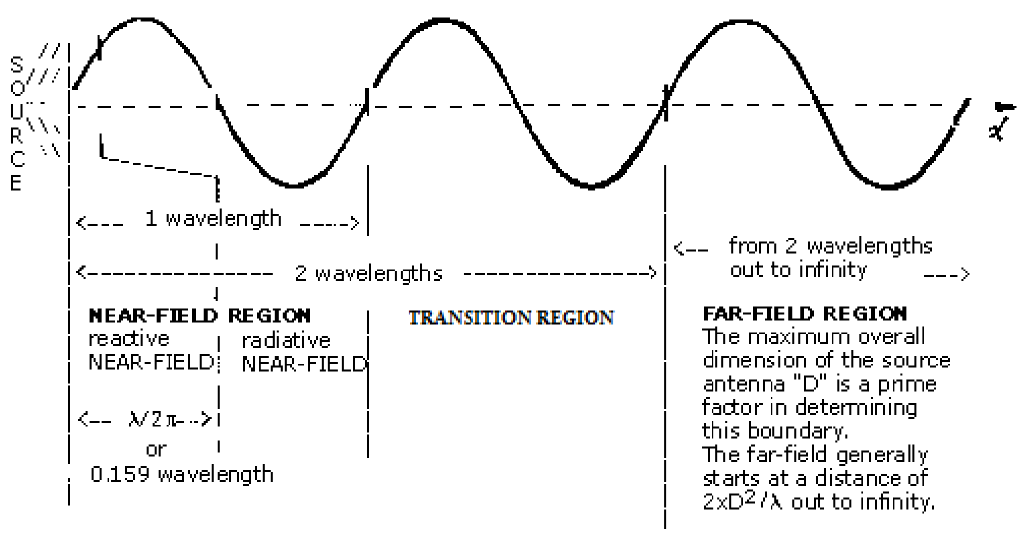


Figure 12a. Antenna Regions - Wave Representation

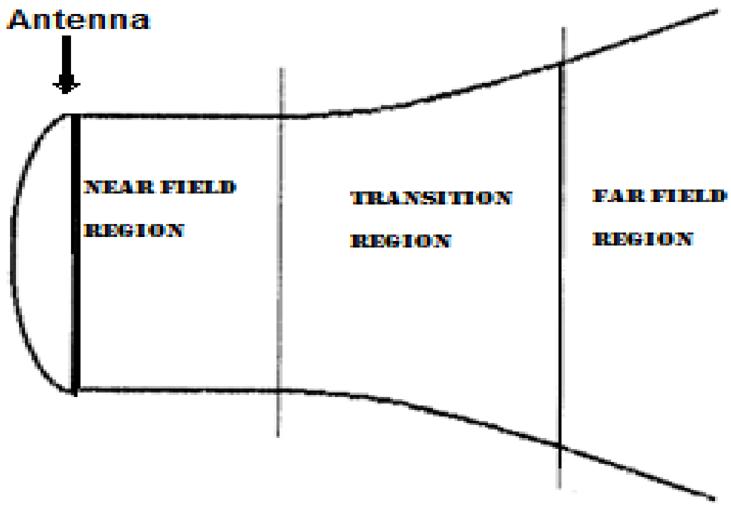


Figure 12b. Antenna Regions - Spatial Representation

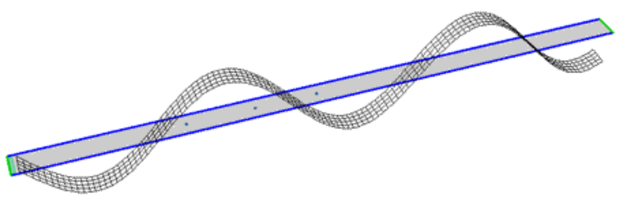


Figure 13. Uniform Plane Wave

In the far-field, both the electric and magnetic fields are completely transverse to the direction of propagation and the magnitude of the electric field (E) & magnetic field (H) can be related as in equation 8:

$$Z = E\ (V/m)\ /H\ (A/m)$$

Equation 8. Electric Field (E) & Magnetic Field (H) Correlation Calculation

Where Z is the free space impedance of 377 Ω.

2 Near-Field (Fresnel Region): At close distances to an antenna, the field does not decrease with distance as is the case in the far-field; instead, it remains relatively constant. In the near-field, the electromagnetic fields are not completely transverse to the direction of EMF propagation, the two fields do not approximate a uniform plane wave, and the two fields cannot be related to each other by free space impedance of 377Ω. In the near-field of an antenna, both the magnetic and electric radiation fields are complex as compared to that of the far-field. For example, in the near-field of dipoles, impedance is very high as compared to the far-field impedance of 377Ω; in this case, the magnetic field is small with respect to the tangential electric field, as compared to their relationship in the far-field.

3 Far Field Power Density: Maximum power density at a given distance from an antenna is easily calculated with equation 9:

$$Power\ Density\ (W/m^2) = \frac{P_{ave}\ G_{abs}}{4\ \pi\ [D(meters)]^2}$$

Equation 9. Far-Field Power Density Calculation

Where D is the distance from the antenna. Simply put, the power density is inversely propiogate with the distance from the antenna squared. This relationship holds true for all types of antennas. By rearranging Equation 9, we can solve the equation for D and thereby determine the distance from an antenna where the power density equals that of the MPE. An example of Equation 10 in use is provided in Appendix H, Example 1.

$$D(meters) = \sqrt{\frac{P_{ave}(watts)\ G_{abs}}{4\ \pi\ MPE\ (\frac{W}{m^2})}}$$

Equation 10. MPE Distance Calculation

4 Boundary Definition: There are no distinct lines separating the three antenna regions, to some extent assignment of the far-field region boundary is arbitrary. There are numerous techniques used to define this region implementing evaluation of amplitude errors, phase errors, and comparison of the transverse and radial electric fields. For the purposes of the BE technician, the following should be sufficient:

For:

$$(f > 300\ MHz):\ \text{Far-Field} \geq [2 \times L^2] / \lambda$$

Equation 11. Microwave RF Far-Field Boundary Calculation

$$(300\ MHz \geq f \geq 30\ MHz):\ \text{Far-Field} \geq 5 \times L$$

Equation 12. Resonance Range Far-Field Boundary Calculation

$$(30\ MHz > f):\ \text{Far-Field} \geq 1.6 \times \lambda$$

Equation 13. Electrostimulation Far-Field Boundary Calculation

Where L is the longest dimension of the antenna and λ is the signal wavelength. Note that for the three equations given there is not a specified unit for antenna length, L, or signal wavelength, λ; any unit can be used provided that the same units are used for both parameters. See Example 1 of Appendix H for an example of Equation 11 in use.

5 Near Field Power Density: Unfortunately, calculations to determine power densities in the near-field are not as simple as in the case of the far-field. For aperture antennas, like the one in Figure 16, and characteristic of most antennas operating at or above 300 MHz, we suggest using Equation 14 to estimate the maximum power density on the main beam axis. Example 2 of Appendix H illustrates the use of this equation.

$$\text{Near Field Power Density} = (4 \times P_{av}) / (\text{Antenna Area})$$

Equation 14. Near Field Power Density Calculation

6 Transition Region: The transition zone contains characteristics of both the far-field and near-field. Generally, the electric and magnetic field are somewhat transverse to the direction of propagation and therefore, they are approximately related by free space impedance of 377Ω. Additionally, power density does decrease with distance from the antenna, but its level cannot be accurately predicted with the far-field equation.

7 Field Measurements: The most practical use of understanding antenna regions is its application to performing measurement surveys. Generally, when performing measurements in the near-field it is necessary to measure both the electric and magnetic field components to ascertain accurate information about the field. Practically, this should be done for emitters that radiate below 100 MHz, while surveying in the near-field. For measurements in the far-field and usually the transition region, the electric and magnetic field are related by free space impedance of 377Ω in the far field it is much easier to measure E Field than the H Field; therefore there is no need to measure both fields.

(c) Radiation Pattern

1 General: This important antenna characteristic determines how energy is distributed in space. Several patterns are fairly common as noted below:

- An omnidirectional or broadcast-type pattern is used whenever all directions must be covered equally. The horizontal-plane pattern is approximately circular while the vertical-plane pattern may be squeezed down to increase area coverage.

- A pencil-beam pattern is typically used when the radiation must be concentrated in as narrow an angular sector as possible. The widths of the beam in the two principal planes are essentially equal.

- A fan-beam pattern is similar to a pencil-beam pattern except that the beam cross section is elliptical rather than circular in shape. The beam width in one plane may be considerably broader than the beam width in the other plane.

- A shaped-beam pattern is used when the pattern in one of the principal planes must have a special shape for the type of coverage required. An example is the "cosecant-squared" pattern used to provide a constant radar return over a wide range of vertical angles. Of course, there are others that do not fall into any of these categories: figure-eights, carotids, split-beams, multiple lobes, etc.

2 Beam Width: The important characteristic of simple antenna patterns (fan, pencil, shaped, etc.) can be specified in terms of the beam width in the two principal planes: horizontal and vertical. The beam width of a radiation pattern is the angular width of the beam defined by the points where power is one half of maximum beam power. Beam width is a characteristic more commonly associated with aperture antennas; however, it can be defined for omni-directional antennas as well. Antenna beam width is closely related to antenna gain. Naturally, antennas with large gains will have small beam widths, and conversely, antennas with small gains will have large beam widths. Normally, beam widths are specified in the horizontal and vertical planes for rectangular aperture antennas and wire antennas. A single circular width is given for circular apertures. Beam width is typically specified in degrees.

3 Beam pattern shape, gain, typical beam widths, and pictorial examples for common antennas are given in Appendix G.

4. The Hazards of EMF

Potential Hazards: The current USAF Standard (AFOSH Standard 48-9,) is designed to protect against potential hazards associated with exposure to EMF fields. The hazards are separated into three overlapping areas:

- Electro-stimulatory effects (i.e., painful nerve impulses) evoke the need for MPEs between 3 kHz - 5 MHz.

- Thermal effects (i.e., increased body temperature) evoke the need for MPEs between 100 kHz - 3 GHz.

- Skin heating effects (i.e., painful skin absorption) evoke the need for MPEs between 10 GHz - 300 GHz.

Note: The overlapping is based upon mixed responses by experimental subjects.

(1) Consequences of low-frequency (LF) fields (3 kHz - 5 MHz)

(a) Low-frequency magnetic fields cause currents to flow in the body. In the case of low-frequency electric fields, we speak of “induced body currents”. The predominant effect is a stimulus of nerve and muscle cells.

(b) Low-frequency limits are based on the current density model which is used to explain the dependency of the stimulating current density on frequency. In the case of low-frequency fields, we mostly note stimulation of sense, nerve and muscle cells as a function of frequency. The greater the field strength, the more pronounced the effects. While the human organism is capable of withstanding weak interactions, more intense signals can produce irreversible damage to the health under certain circumstances. There are a number of scientific studies underway around the globe to assess the consequences of low-frequency fields.

(c) Static fields can produce familiar “static electricity” which causes our hair to stand up as well as electrostatic discharges. Static electricity can be the catalyst for other hazards such as fire. In industrial settings such as paint or powder mixing facilities as well as hospitals; the use of antistatic safety boots to prevent a buildup of static charge due to contact with the floor is standard practice. These boots have soles with good conductivity.

(d) Health consequences occur only through exposure to very powerful magnetic fields (> 4 Tesla). For the limits, the force influences on metallic objects are relevant. Secondary effects of fields can indirectly influence our health. For example, cell phones can affect navigation equipment in airplanes. Electronic implants such as pacemakers can also be impaired by radiation from EMF equipment and antennas. This danger is further discussed below in the “Indirect Biological Hazards” section (page 30 para. (7)).

(2) Current Density Consequences

(a) Below 1 mA/m^2: No clear effects; range of natural background current densities in most bodily organs.

(b) 1-10 mA/m^2: Subtle biological influences such as altered calcium flows or inhibition of melatonin production (which controls our day/night body rhythm, etc.). The background current density of the heart and brain are in this range.

(c) 10-100 mA/m^2: Confirmed effects, e.g. changes in protein and DNA synthesis, changes in enzyme activity, clear visual (magnetophosphenes) and possible nervous effects; healing processes in broken bones can be accelerated or halted.

(d) 100-1000 mA/m^2: Sensitivity of the central nervous system is altered; this is a range in which effects are observed in all tissue that is capable of stimulus.

(e) Over 1000 mA/m^2: Minor to severe impairments of heart functioning; acute damage to health.

(3) Consequences of EMF fields at frequencies between 1 MHz - 10 GHz

(a) EMF fields between 1 MHz and 10 GHz will penetrate bodily tissue and heat it due to the absorbed energy. The depth of penetration decreases at higher frequencies. Since the heating occurs from the inside, it is not perceived (or it is perceived too late) since we perceive heat primarily through receptors situated near the skin surface. Our bodies are capable of handling heating as a result of small amounts of EMF energy through its normal thermoregulation processes.

(b) EMF fields above 10 GHz are absorbed at the skin surface (example: Active Denial). Only a small portion of the energy penetrates into the underlying tissue. Very high field strengths are needed to produce problems such as cataracts or skin burns. They will not occur through normal, everyday exposure to radiation, but they can occur in the immediate vicinity of powerful radar systems, for example. Such facilities are generally cordoned off over a wide area with warning signs and other controls.

(4) Frequency Response Differences

(a) 1 - 30 MHz: Great depth of penetration into the human body; not uniform in distribution of absorbed power.

(b) 30 - 300 MHz: “Resonance range”; here, the wavelengths are very close to the typical human size (or the size of individual body parts). The field energy is absorbed to a great extent. The lowest MPE exposure limits are found in this frequency range.

(c) 300 MHz - 10 GHz: The depth of penetration of EMF into the human body decreases in this range.

(d) Over 10 GHz: Increase in temperature at the body surface (skin burns are possible.) Energy absorption in tissue due to EMF fields is characterized using the specific absorption rate (SAR) within a certain mass of tissue. This is measured in units of watts per kilogram [W/kg]. Limits for EMF fields are based on the SAR. The long-term effects of low-intensity EMF radiation are currently under study as part of an international EMF project sponsored by the World Health Organization (WHO). Previous scientific studies have not managed to agree on whether exposure to EMF fields can cause cancer or make it more likely. The fact that EMF exposure influences cells, enzyme activity and genes has been shown, under certain conditions (frequency, signal shape, intensity). However, it is still unclear whether any of these effects actually influence human health.

(e) The extent to which a body part will absorb heat as a result of EMF fields is dependent on the blood circulation and thermal conductivity. For example, kneecaps and the lenses in our eyes are particularly susceptible since they have little or no circulation. In contrast, the heart, lungs and skin are not very sensitive due to their excellent circulation.

(5) High-Power Microwave Weapon Hazards: As a new field of study; there is limited scientific data to develop human exposure guidance associated with HPM bioeffects. Most of the available studies used nonhuman species and included lethality, stun and behavioral studies as well as other experiments, e.g., central nervous system effects and in vitro cellular changes. Auditory sensations produced by pulsed microwave radiation have been documented in both humans and laboratory animals. Nonetheless, the data were considered when developing the TLV/MPEs.

(6) Induced and Contact Current Limits: The current limits included in these MPEs assume that electrostimulation is the primary biological interaction at frequencies from 0.03-0.1 MHz, while heating is the primary mechanism above 0.1 MHz.

From 0.1 to 100 MHz, the MPE will limit SAR in the extremities of the limbs to less than 20 W/kg, as averaged over a cubic volume containing 10 g of tissue. The limbs, especially the ankles and wrists, have the smallest cross-sectional areas in the body and the current density (and associated heating) will be highest there. The 500 mA ceiling value on induced and contact currents is considered adequately protective against adverse effects.

(7) Indirect Biological Hazards: Many electronic devices used in manufacturing processes, telecommunications, audio and video systems, and automotive and aircraft transportation are vulnerable to Radio Frequency Interference (RFI). The greatest concern about RFI in terms of potential impacts on human health is the vulnerability of many electronic medical devices either worn by patients or used in clinical practices. RFI problems have been associated with the incorrect operation of cardiac pacemakers, defibrillators, drug infusion pumps, apnea monitors, and a diversity of other medical devices such as nerve stimulators, electrically powered wheelchairs, and motorized scooters. See MIL-STD-461F, 10 December 2007 "*Requirements For The Control Of Electromagnetic Interference Characteristics Of Subsystems And Equipment*" for additional DoD information.

Technology exists to "harden" devices to make them considerably less sensitive to RFI and most devices are less vulnerable than they were twenty years ago. However, a number of widely used medical devices are still vulnerable to RFI at much lower field levels that are less than the MPEs for RF-microwave radiation (IEEE, 2005b). Based on the available technical information and guidance from FDA-CDRH and the ACGIH, it is recommended that medical electronic equipment or the entry of individuals wearing medical devices subject to RFI is restricted to locations where the strength of RF fields at frequencies up to 3 GHz is not expected to interfere with operation of the devices based on manufacturers' specifications (typically field levels less than 3-10 V/m that meet RFI compliance requirements).

Base-level Bioenvironmental Engineering will continue to assist in locating and defining these areas and assisting on choosing the proper postings. Supervisor's and the POCs for potential equipment creating RFI need to inform Bioenvironmental Engineering of this new equipment so that it can be fully evaluated.

The ultimate responsibility for pacemaker safety lies with the individuals with the devices. Personnel with devices that could potentially be affected by EMF, should contact their personal physicians for specific tolerance data.

(8) X-Ray Emissions: Radar units contain klystron, magnetron, and thyratron tubes that emit ionizing radiation as a result of high voltage being applied to the tube. Radar units also have interlock systems in the area where the high voltage is located; however, many times the interlocks are bypassed by maintenance personnel during testing. For this reason it is important to insure that maintenance personnel are not being overexposed to ionizing radiation when cabinet doors are open. Another consideration to be made during survey of x-ray emissions is that an RF-shielded survey instrument is used. A Victoreen Model 451 will not give accurate readings; the 471RF/D model, or equivalent, should be used instead. To perform a survey, measurements are taken on all sides of the transmitter cabinet, especially around seals to removable panels. If possible, remove panels that are removed routinely and check for leakage. Caution should be observed when measuring x-ray emissions with panels removed because of the potential for high voltage arcing. It is good practice not to advance the meter beyond the limits of the cabinet frame. X-ray levels are not expected to exceed 2 mR/hr (milliroentgens/hour). For

more information on this topic, please consult *USAFSAM Report IOH-SD-BR-SR-2005-0004 "Bioenvironmental Engineer's Guide to Ionizing Radiation."*

(9) Electromagnetic Interference: With the multitude of EMF emitters and other electronic equipment located on the typical Air Force installation, it is common to find many cases of electromagnetic interference. Non health hazards like electromagnetic interference come up often due to all the communication EMF in today's world. Though BEs are not accountable for the control of non-hazardous electromagnetic interference, they are often consulted about these problems. As consultants, USAFSAM has had the opportunity to hear a vast array of stories concerning electromagnetic interference over the years. Stories of interference with broadcast signals, cell phone interference and poor digital television reception are some of the common ones. In the vast majority of EMF interference cases, there are no personnel hazards, but, people often associate electromagnetic interference with the potential for personnel hazards. EMF average power density levels in the $\mu W/cm^2$ range can easily cause interference with common electronic equipment, but, interference phenomena are rarely associated with a health hazard. Having an up-to-date installation inventory of EMF is the only way to track sources (even non-hazardous) and will limit reinvestigating cyclic complaints. Where EMF interference is creating non-health hazard problems, recommend that policy set by Air Force Safety Center (HQ AFSC) will address these situations per AFOSH 48-9, Section 2.6.

(10) Inductive Capacitive Coupling: Capacitive (electric) fields are voltage fields. The effects depend upon the amount of capacitance existing between exposed portions of the noisy circuit and the noise-free circuit. The power transfer capabilities are directly proportional to frequency. Thus, high-frequency components are more easily coupled to other circuits. Capacitive coupling is relatively easy to shield out by placing a grounded conducting surface between the interfering source and the susceptible conductor.

(11) Coupling By Radiation: Almost any wire in an airframe can, at some particular frequency, begin to act like an antenna through a portion of its length. Inside an airframe, however, this occurs only at very high frequencies. At high frequencies, all internal leads are generally well shielded against pickup of moderate levels of radiated energy. Perhaps the only cases of true inside-the-aircraft radiation at high frequencies and below occur in connection with unshielded or inadequately shielded transmitter antenna leads.

(12) Interference Coupling: The amount of the variation in the current directly affects variability in the magnetic field surrounding a conductor; and is dependent upon the nature of the current. When the conductor is a power lead to an electric motor, all the frequencies and amplitudes associated with broadband interference are present in the magnetic field. When the lead is an AC power lead, a strong sinusoidal magnetic field is present. When the lead is carrying switched or pulsed currents, extremely complex broadband variations are present. As the magnetic field cuts across a neighboring conductor, a voltage replica of its variation is induced into the neighboring wire. This causes a current to flow in the neighboring wire. When the neighboring wire leads to a sensitive point in a susceptible receiver, serious interference with that receiver's operation can result. Similarly, a wire carrying a steady, pure DC current of high value sets up a magnetic field capable of affecting the operation of equipment whose operation is based upon the earth's magnetic field. Shielding a conductor against magnetic induction is both

difficult and impractical. Nonferrous shielding materials have little or no effect upon a magnetic field. Magnetic shielding that is effective at low frequencies is prohibitively heavy and bulky.

(13) Complex Coupling: Some examples of interference coupling involve more than one of the types (interference, induction, or radiation) just discussed. When more than one coupling occurs simultaneously, corrective actions, such as bonding, shielding, or filtering, used to correct one type of coupling can increase the coupling capabilities of another type of coupling. The result may be an increase in the transfer of interference. For example, an unbended, unfiltered DC motor can transfer interference to a sensitive element by interference, inductive coupling, capacitive coupling and by radiation. Some frequencies are transmitted predominately by one form of coupling and some frequencies by others. At still other frequencies, all methods of transmission are equally effective. On the motor used in the example above, bonding almost always eliminates radiation from the motor shell. It also increases the intensity in one of the other methods of transmission, usually by conduction. The external placement of a low-pass filter or a capacitor usually reduces the intensity of conducted interference. At the same time, it may increase the radiation and induction fields. This occurs because the filter appears to interference voltages to be a low-impedance path across the line. Relatively high interference currents then flow in the loop formed between the source and the filter. For complex coupling problems, multiple solutions may be required to prevent the interference.

5. Standards

a. History

(1) In 1958 DoD adopted its first standard for exposures to EMF. The first standard set a Permissible Exposure Limit (PEL) of 50 mW/cm^2 for frequencies between 10 MHz - 300 GHz. The standard was based on exposures averaged over any six minute period of time. The 10 mW/cm^2 PEL originated from physiological consideration that whole-body exposure to humans to a level of about 100 mW/cm^2 or more would cause a mild-to-severe increase in thermal load (depending on the load), and by application of a safety factor of 10. The guide was based on a belief that nearly all workers could be exposed to EMF at 10 mW/cm^2 or lower during a normal series of working days without adverse effects. Adoption of the guide recognized that electromagnetic fields at or below the PEL could cause physiological effects, but the effects had no adverse medical consequences.

(2) Since the first standard was introduced, there has been considerable research to indicate that the human body selectively absorbs EMF dependent on frequency. In 1982, the American National Standards Institute (ANSI) developed a frequency dependent standard. The standard is based on observed thermal effects from a mean whole-body specific-absorption rate (SAR) of 4 W/kg; with a safety factor of 10, the standard is 0.4 W/kg. The SAR is a measure of the absorbed energy from an incident electromagnetic field and is normally expressed as energy absorbed per unit volume (watts/kilogram), where 1 kilogram is equal to approximately 1000 cm^3 (for most biological systems). The standard also contains a partial body limit, spatial peak SAR, that is based on 8 W/kg averaged over any one gram of tissue.

(3) Today's standard has exposure limits for electric fields and magnetic fields that are whole-body and time averaged and to induced and contact currents in order to protect against

established adverse health effects. Standard Limits are expressed in terms of Maximum Permissible Exposure (MPE). Specifically in the frequency range of 3 kHz - 5 MHz, the rules minimize adverse effects associated with electro-stimulation; in the frequency range of 100 kHz - 300 GHz, the rules protect against adverse health effects associated with heating. In the transition region of 0.1 to 5 MHz, each of the two sets of rules must be applied. In this transition region the rules based on heating will be more restrictive for long-term exposures to continuous wave (CW) fields, while the rules based on the effects of electro-stimulation (rather than body heating) will be more restrictive for short-term exposure, e.g., short isolated pulses of low duty factor. The induced and contact currents MPEs are related to the strength of the electric field.

(4) The localized SAR value within a given entity is dependent on frequency, modulation, amplitude and polarization of an incident EMF field; the properties of the material; and the configuration of the material with respect to the incident field. For entities that are complex in shape and variant in distribution of its constituents, distribution of local SAR is difficult to determine. As a result, the concept of whole-body SAR was developed, because this quantity is easy to measure experimentally without the need to understand the SAR internal distribution.

(5) The whole-body SAR is highly dependent on the size of the body. Figure 14 demonstrates this phenomenon by comparison of the EMF absorption of three different size bodies: a man, a rat, and a mouse. The peak absorbance of a mouse (at ~1050 MHz) is 5.6 times that of man (at ~ 70 MHz).

Note also from Figure 14, how EMF absorption for man varies with frequency. At 10 MHz and below, the human body is transparent to EMF absorbing very little as compared to the frequencies near 70 MHz. While for frequencies above 1000 MHz, the absorbance factor is rather constant.

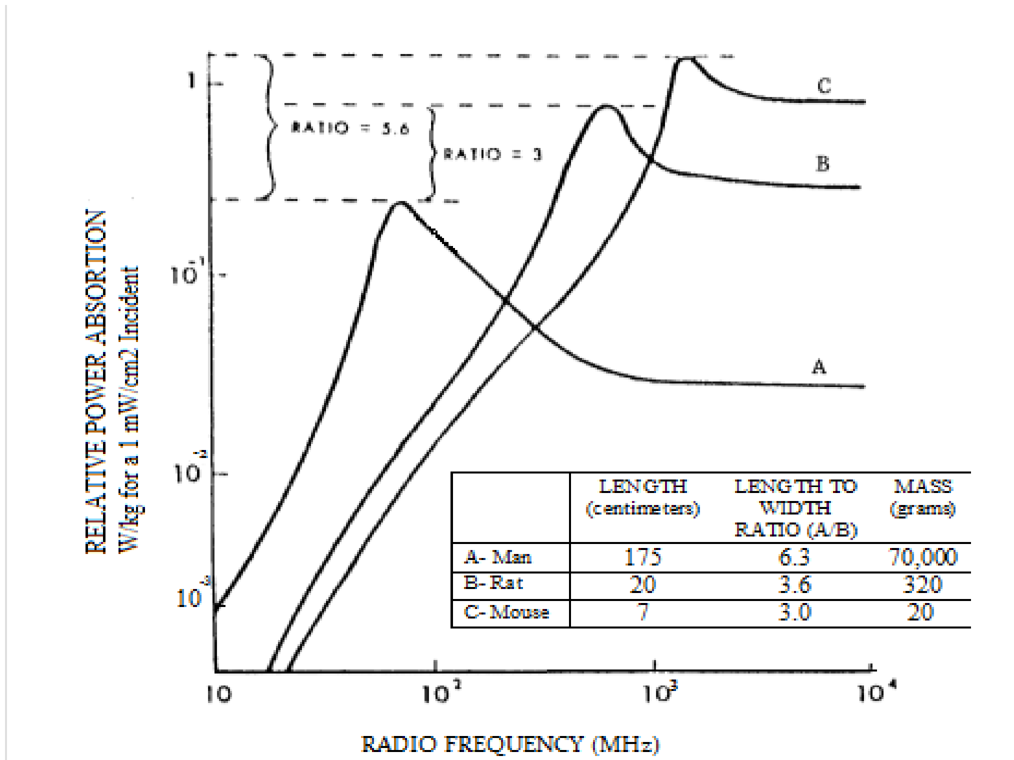


Figure 14. RFR Power Absorption Scaling Factors

b. Maximum Permissible Exposure (MPE) Values

(1) MPE values have been based upon a whole-body specific absorption rate (SAR) of 0.4 watts per kilogram (W/kg), and incorporate a safety factor of 10 or more below a SAR of 4.0 W/kg, which is the conservative threshold for the occurrence of potentially deleterious health effects in humans. SAR as the basis is only applicable for 100 kHz – 3 GHz.

(2) MPEs are expressed in terms of measurable field parameters as a convenient correlation to the SAR. These field parameters include root-mean-square (rms) electric field (E) and magnetic (H) field strengths, their squares, or the plane-wave equivalent power densities (S) associated with these fields, and peak electric field strengths. Induced and contact current limits that can be associated with exposures to such fields are also established.

(3) Section A from the AFOSH 48-9 Tables A3.1 (page 36) and A3.2 (page 39) below refer to time-averaged exposure values obtained by spatially averaging S, or the mean squared E and H values, over an area equivalent to the vertical cross-section of the human body (projected area). In the case of partial-body exposure or non-uniform fields, these MPEs, Table A3.1, may be exceeded. However the increased MPE must comply with the exposure limits listed in the additional sections of Table A3.1 and Table A3.2.

(4) A Bioenvironmental Engineer may contact USAFSAM/OE for guidance when evaluating exposure incidents to determine if the MPE may be exceeded.

(5) MPEs are derived quantities that are based upon the basic restriction, i.e. the SAR. Commanders will avoid exposure of personnel to EMF levels in excess of the applicable MPE, except where necessary for medical treatment, or in training or operation of a directed energy weapon used in accordance with AFI 91-401, or where mission requirements necessitate such exposure. Note: Do not infer that mission requirements can justify allowing over-exposures. Always limit personnel EMF exposure to levels that are below the applicable MPEs.

Upper Tier MPEs: These limits (formerly known as "controlled") are presented as a function of frequency and are based on a SAR of 0.4 W/kg. The limits were developed to control human exposures to electromagnetic energy at frequencies ranging from 0 kHz - 300 GHz, and to limit the localized SAR occurring in the feet, ankles, wrists, and hands of personnel due to exposure to such fields or contact with objects exposed to such fields. MPEs are given in terms of rms electric (E) and magnetic (H) field strengths, equivalent plane-wave free space power densities (S), flux density, (B) and induced currents (I) in the body. Installations with EMF programs shall always utilize upper tier MPEs.

Table 4. MPEs for the Upper Tier (AFOSH 48-9 Table A3.1.)

A. MPE for Upper Tier

Frequency Range (f) (MHz)	RMS electric field (E)[a] (V/m)	RMS magnetic field strength (H)[a] (A/m)	RMS power density (S) E-field, H-field (W/m^2)	Averaging time $\|E\|^2$, $\|H\|^2$ or S (min)
0.1 - 1.0	1842	$16.3/f_M$	$(9000, 100\,000/f_M^2)$[b]	6
1.0 – 30	1842/f	$16.3/f_M$	$(9000/f_M^2, 100\,000/f_M^2)$	6
30 – 100	61.4	$16.3/f_M$	$(10, 100\,000/f_M^2)$	6
100 – 300	61.4	0.163	10	6
300 – 3000			$f_M/30$	6
3000 – 30 000			100	$19.63/f_G^{1.079}$
30 000 – 300 000			100	$2.524/f_G^{0.476}$

NOTE-f_M is the frequency in MHz, f_G is the Frequency in GHz

[a]For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the MPEs in section A of this table. For non-uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body (projected area), or a smaller area depending on the frequency, are compared with the MPEs in section A of this table.

[b]These plane-wave equivalent power density values are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

For S: The left column is the averaging time for $|E|^2$, the right column is the averaging time for $|H|^2$. For frequencies greater than 400 MHz, the averaging time is for power density S.

B. Electric field MPE- whole body exposure:
F= 3 kHz to 100 kHz

Frequency range (kHz)	E (rms) (V/m)
3 – 100	1842

C. MPE for exposure of head and torso:
F= 3 kHz to 5 MHz

Frequency range (kHz)	B_{rms} (mT)	H_{rms} (A/m)
3.0 – 3.35	2.06/f	1640/f
3.35 – 5000	0.615	490

NOTE—f is expressed in kHz. The averaging time for an rms measurement is 0.2 seconds.

Table 4. MPEs for the Upper Tier (AFOSH 48-9 Table A3.1.) (continued)

D. MPE for limbs:
F= 3 kHz to 5 MHz

Frequency range (kHz)	B_{rms} (mT)	H_{rms} (A/m)
3.0 – 3.35	3.79/f	3016/f
3.35 - 5000	1.13	900

NOTE—f is expressed in kHz.

E. RMS induced and contact current limits for continuous sinusoidal waveforms
F=3 kHz to 100 kHz

Condition	Persons in Upper Tier environments (mA)
Both feet	2.00f
Each foot	1.00f
Contact, grasp[b]	1.00f
Contact, touch	0.50f

NOTE 1—f is expressed in kHz.

NOTE 2—Limits apply to current flowing between the body and a grounded object that may be contacted by the person.

NOTE 3—The averaging time for determination of compliance is 0.2 s.

[b]The grasping contact limit pertains to Upper Tier environments where personnel are trained to make grasping contact and to avoid touch contacts with conductive objects that present the possibility of painful contact.

F. RMS induced and contact current limits for continuous sinusoidal waveforms
F=100 kHz to 110 MHz

Condition	Persons in Upper Tier Environments (mA)
Both feet	200
Each foot	100
Contact, grasp[b]	100
Contact, touch	50

NOTE 1—Limits apply to current flowing between the body and a grounded object that may be contacted by the person.

NOTE 2—The averaging time for determination of compliance is 6 minutes.

[b]The grasping contact limit pertains to Upper Tier environments where personnel are trained to make grasping contact and to avoid touch contacts with conductive objects that present the possibility of painful contact.

Table 4. MPEs for the Upper Tier (AFOSH 48-9 Table A3.1.) (concluded)

G. Basic Restrictions (BRs) applying to various regions of the body		
Exposed tissue	f_e (Hz)	E_0 (rms) (V/m)
Brain	20	1.77×10^{-2}
Heart	167	0.943
Extremities	3350	2.10
Other tissue	3350	2.10

H. BRs for frequencies between 100 kHz and 3 GHz		
		Persons in Upper Tier Environments - SAR[c] (W/kg)
Whole-body exposure	Whole-body average (WBA)	0.4
Localized exposure	Localized (peak spatial-average)	10[c]
Localized exposure	Extremities[d] and pinnae	20[c]
[b]SAR is averaged over the appropriate averaging times as shown in section A of this table.		
[c]Averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube).*		
[d]The extremities are the arms and legs distal from the elbows and knees, respectively.		

I. Relaxation of the power density MPEs for localized exposures (partial-body exposure)		
Frequency Range (f) (MHz)	Peak Value of Mean Squared Field	Equivalent Power Density (W/m^2)
.003 – 300	$<20 E^2$ or $20 H^2$ *	-
300 – 3000	-	200
3000 – 96 000	-	$200(f_G/3)^{1/5}$
f_M> 96 000	-	400
NOTE- f_M is the frequency in MHz, F_G is the Frequency in GHz		
* E and H are the spatially averaged values from section A of this table		

J. Pulsed EMF Fields (apply only when there are less than 5 pulses with the averaging time).		
Frequency Range (f) (MHz)	Peak Electric Field (E) (kV/m)	Power Density Pulse for Pulse Durations < 100 msec (W/m^2)
0.1 – 300 000	100	$(MPE)(T_{avg})/(5)$(pulse width)

K. Threshold Limit Values (TLVs) for sub-radio frequency Magnetic Fields (DC up to 3 kHz)		
Frequency Range (f)	TLV	Body Part of Point of Application
1 - 300 Hz	$60/f_k$ mT (ceiling value)	Whole-body Exposure
1 - 300 Hz	$300/f_k$ mT (ceiling value)	Arms and Legs
1 - 300 Hz	$600/f_k$ mT (ceiling value)	Hands and Feet
300 Hz – 3 kHz	0.2 mT (ceiling value)	Whole Body and Partial Body
NOTE- f_k is the frequency in kHz, DC is Direct Current		

Lower Tier MPEs: These limits are presented as a function of frequency and are based on a SAR of 0.08 W/kg lower tier (formerly known as "uncontrolled") exposures can occur in areas where individuals would have no knowledge or control of their exposure. These locations would include living quarters or workplaces where there are no expectations that the exposure levels may exceed those shown in the AFOSH 48-9 table A3.2.

Action Level: Any exposures in excess of those indicated in Table 5 (AFOSH 48-9 table A3.2) shall require the adoption of an EMF safety program. Where installations have emitters that can create power densities above the action level/lower tier MPE; then you must adopt a safety program.

Table 5. MPEs for Lower Tier (AFOSH 48-9 Table A3.2.)

L. MPEs for Lower Tier					
Frequency Range (f) (MHz)	RMS electric field (E)[a] (V/m)	RMS magnetic field strength (H)[a] (A/m)	RMS power density (S) E-field, H-field (W/m^2)	Averaging time $\|E\|^2$, $\|H\|^2$ or S (min)	
0.1-1.34	614	$16.3/f_M$	$(1000, 100\,000/f_M^2)$[c]	6	6
1.34–3	$823.8/f_M$	$16.3/f_M$	$(1800/f_M^2, 100\,000/f_M^2)$	$f_M^2/0.3$	6
3–30	$823.8/f_M$	$16.3/f_M$	$(1800/f_M^2, 100\,000/f_M^2)$	30	6
30–100	27.5	$158.3/f_M^{1.668}$	$(2, 9\,400\,000/f_M^{3.336})$	30	$0.0636\, f_M^{1.337}$
100–400	27.5	0.0729	2	30	30
400-2000	-	-	$f_M/200$	30	
2000-5000	-	-	10	30	
5000-30 000	-	-	10	$150/f_G$	
30 000-100 000	-	-	10	$25.24/f_G^{0476}$	
100 000-300 000	-	-	$(90f_G-7000)/200$	$5048/[(9f_G-700)f_G^{0.476}]$	

NOTE-f_M is the frequency in MHz, F_G is the Frequency in GHz

[a]For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the MPEs in section A of this table. For non-uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body (projected area), or a smaller area depending on the frequency, are compared with the MPEs in section A of this table.

[c]These plane-wave equivalent power density values are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

Electric field MPE- whole body exposure: F= 3 kHz to 100 kHz

Frequency range (kHz)	E (rms) (V/m)
3 – 100	614

Table 5. MPEs for Lower Tier (AFOSH 48-9 Table A3.2.) (continued)

M. MPE for exposure of head and torso: F= 3 kHz to 5 MHz		
Frequency range (kHz)	B_{rms} (mT)	H_{rms} (A/m)
3.0 – 3.35	0.687/f	547/f
3.35 – 5000	0.205	163
NOTE—f is expressed in kHz. The averaging time for an rms measurement is 0.2 seconds.		

N. MPE for limbs: F= 3 kHz to 5 MHz		
Frequency range (kHz)	B_{rms} (mT)	H_{rms} (A/m)
3.0 – 3.35	3.79/f	3016/f
3.35 — 5000	1.13	900
NOTE—f is expressed in kHz.		

P. Root Mean Square (RMS) induced and contact current limits for continuous sinusoidal waveforms- F=3 kHz to 100 kHz	
Condition	Persons in Lower Tier environments (mA)
Both feet	0.90f
Each foot	0.45f
Contact, grasp[b]	-
Contact, touch	0.167f
NOTE 1—f is expressed in kHz.	
NOTE 2—Limits apply to current flowing between the body and a grounded object that may be contacted by the person.	
NOTE 3—The averaging time for determination of compliance is 0.2 s.	

Q. RMS induced and contact current limits for continuous sinusoidal waveforms F=100 kHz to 110 MHz	
Condition	Persons in Lower Tier Environments (mA)
Both feet	90
Each foot	45
Contact, grasp[b]	-
Contact, touch	16.7
NOTE 1—Limits apply to current flowing between the body and a grounded object that may be contacted by the person.	
NOTE 2—The averaging time for determination of compliance is 6 minutes.	

R. Basic Restrictions (BRs) applying to various regions of the body		
Exposed tissue	f_e (Hz)	E_0 (rms) (V/m)
Brain	20	5.89×10^{-3}
Heart	167	0.943
Extremities	3350	2.10
Other tissue	3350	0.701

Table 5. MPEs for Lower Tier (AFOSH 48-9 Table A3.2.) (concluded)

S. BRs for frequencies between 100 kHz and 3 GHz		
		Persons in Lower Tier Environments SAR[c] (W/kg)
Whole-body exposure	Whole-body average (WBA)	0.08
Localized exposure	Localized (peak spatial-average)	2[c]
Localized exposure	Extremities[d] and pinnae	4[c]
[c]Averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube).*		
T. Relaxation of the power density MPEs for localized exposures (partial-body exposure)		
Frequency Range (f) (MHz)	Peak Value of Mean Squared Field	Equivalent Power Density (W/m^2)
.003 – 400	$<20\ E^2$ or $20\ H^2$ *	-
400 – 3000	-	40
3000 – 30 000	-	$18.56(f_G)^{0.699}$
$f_M > 30\ 000$	-	200
NOTE- f_M is the frequency in MHz, f_G is the Frequency in GHz		
* E and H are the spatially averaged values from section A of this table		
U. Pulsed EMF Fields (apply only when there are less than 5 pulses with the averaging time).		
Frequency Range (f) (MHz)	Peak Electric Field (E) (kV/m)	Power Density Pulse for Pulse Durations < 100 msec (W/m^2)
0.1 – 300 000	100	$(MPE)(T_{avg})/(5)(\text{pulse width})$

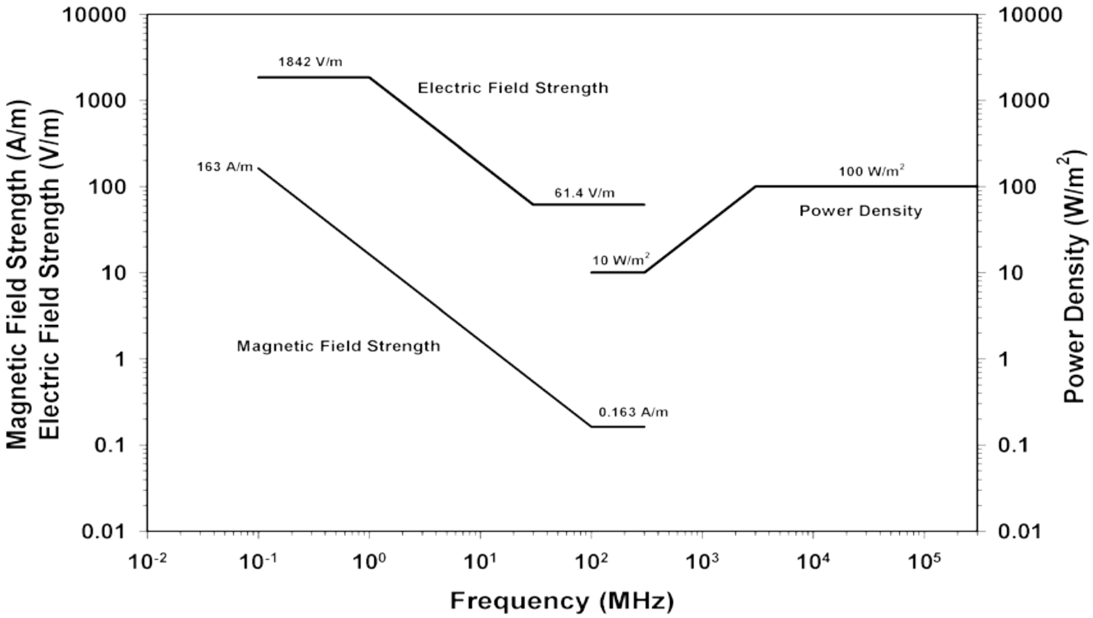


Figure 15. Graphic Representation of MPEs for Upper Tier Environments (Formally "Controlled")

c. Applying the Standard.

(1) Sometimes there is confusion about application of the different exposure MPE criterion before overexposure determinations are made. Total exposure can be quantified as either average power density (W/m^2) or magnetic field strength (A/m) or electric field strength (V/m) over a given averaging period of time or the integrated exposure for a period of time quantified in W-sec/m^2. This approach "integrates" seconds into the MPE calculation.

(2) For example in the 100 to 300 MHz range, a person is considered to have been overexposed if, during any 6 minute period (or 360-second period); the total accumulated exposure exceeds the MPE of 10 mW/cm^2.

(3) Remember, overexposure determinations are based on average power over time. Intermittent exposures, like those from a scanning radar, must be calculated by multiplication of the fixed-beam power density with an additional scanning duty factor. The scanning duty factor is easy to calculate: simply divide the beam width (in the plane of scanning) by the total scanned sector size. For example, the scanning duty factor is 0.0083 for radar that scans horizontally 360^o and has a horizontal beam width of 3^o (calculated as (3° / 360° = 0.0083). For an example of a rotating antenna and calculations; see Appendix H.

d. Future Standards and Research.

(1) There are ongoing efforts for collaboration/harmonization between global EMF health groups. It is important that the IEEE, ICES and ICNIRP continue to try to resolve the differences in health study interpretation.

(2) The long-term health effect of mobile telephone use is another topic of much current research. No obvious adverse effect of exposure to low level radio frequency fields has been discovered. However, given public concerns regarding the safety of cellular telephones and Wi-Fi, further research aims to determine whether any less obvious effects might occur at very low exposure levels.

(3) Personal monitoring of exposure to EMF workers is being improved. Rationale: The exposure patterns of both workers and the general public change continuously, mainly due to the development of new EMF technologies. However, workers encounter industrial sources and exposure situations that lead to much higher energy deposition in the body. When epidemiological studies on EMF workers are performed, it is imperative to monitor adequately their EMF exposure. New instruments are needed to address the lack of adequate measurement tools for evaluating this type of exposure e.g. portable devices suitable for measuring different frequencies and waveforms. In addition, a study of the feasibility of monitoring the personal exposure of EMF workers is required for future epidemiological studies.

AF/SG does not advocate the use of personal detectors or area monitors in Air Force operational environments. This is noted in AFOSH 48-9. In cases where the environment may exceed ten (10) times the MPE, special needs may be addressed and evaluated through consultation with USAFSAM. Use of these types of devices will require written approval from AFMSA/SG on advice of USAFSAM consultants.

6. Training

a. Unit commanders must have established unit EMF safety awareness training programs and ensure workplace supervisors, responsible for the operation of potentially hazardous EMF emitters, develop and implement unit EMF safety awareness training plans.

b. Supervisors who are responsible for the operation of potentially hazardous EMF emitters shall prepare the EMF safety awareness training plan to provide initial training for newcomers and refresher training for system operators, maintenance personnel, and other workers assigned. This includes all installation BE personnel who have the potential to enter these areas for evaluation or investigation (regardless if it is EMF related.)

c. EMF safety awareness training plans typically cover topics including location of emitters, areas that can exceed MPE, control procedures, response to suspected overexposure, bioeffects, risk/hazard assessment, standards, measurements, operation of RF emitter (equipment), PPE, lock-out /tag-out, reports, investigations, risk communication, properties of RF, RF physics and antenna characteristics as appropriate. The training plans must include training and posting requirements at a minimum. Visitors to upper tier MPE areas shall also be provided training.

d. Installations without EMF safety programs.

(1) All personnel with the potential to exceed the Lower Tier MPEs shall be provided initial and refresher training. The depth of information will be commensurate with the potential for exposure as well as the level of responsibility within the EMF safety program.

(2) Where an exposure to levels over the lower tier MPEs occurs:

(a) Installation will implement an EMF Safety program to cover these areas.

(b) A training program shall be established and incorporate information and instruction commensurate to the potential EMF exposure level.

(c) The installation BE flight will assist with the development of training for other personnel as required incorporating the following topics: location of emitters, areas can exceed MPE, control procedures, response to suspected overexposure, bioeffects, risk / hazard assessment, standards, measurements, operation of RF emitter (equipment), PPE, lock-out /tag-out, reports, investigations, risk communication, properties of RF, RF physics and antenna characteristics.

7. Installation Program

a. Verifying EMF Emitter Inventory.

(1) AFOSH Standard 48-9: Familiarity with the responsibilities set forth in the standard is an important first step.

(2) Installation Safety Engineers (AF/SE): A valuable asset to BE and Public Health (PH) is the installation Safety Engineer. AF/SE can assist in identifying emitters on base, assist in interfacing with workplace supervisors and personnel, help emphasize the keys to the installation's EMF program and safety requirements. They can also help promote awareness and understanding of EMF to personnel and initially reduce tensions if a suspected overexposure to EMF is claimed and/or discovered. To work effectively as a team and better communicate, AFOSH Std 48-9 requires installation commanders to involve multiple groups including AF/SE.

b. Inventory Specifics

(1) General: All installations should have an existing database inventory of EMF emitters at their base.

(2) Documentation: All data shall be logged into corresponding Case Files, into DOEHRS or a base level centralized inventory. Now that DOEHRS can accomplish this task, a base level centralized inventory is not necessary. Antenna data (equipment designed to emit EMF) shall also be sent to USAFSAM through the ESOH Service Center for inclusion in the RF Emitter Inventory, **esoh.service.center@wpafb.af.mil**.

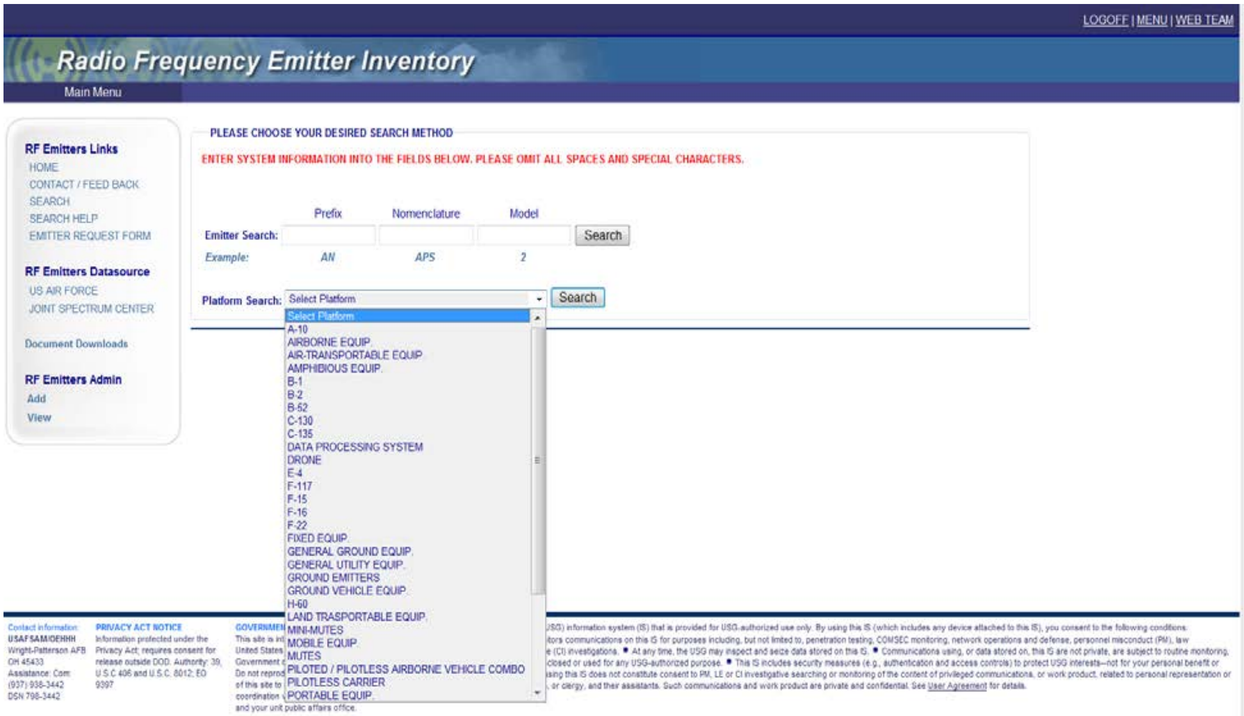


Figure 16. USAFSAM Radio Frequency Emitter Inventory Search and Entry Page

(3) Installation Inventory: An installation inventory of all installation emitters is required by AFOSH Std 48-9. Base inventories shall be periodically reviewed by the BE EMF program manager to ensure EMF emitters are being added (and removed) as equipment changes are made over time. Also, the Inspector General normally reviews the inventory because it provides an overall review of your EMF protection program. The base inventory is a management tool that will help you for future EMF activities. We recommend the following items for the central base inventory:

(a) A summary list of emitters and their hazard distance, hazard code and location.

(b) List of the EMF emitters and POC in their area.

(c) Casefile/database including unit OIs (or Product Data Sheets/technical specifications) for hazardous emitters.

(d) Casefile/database with maps or grid coordinates of ground based emitter locations.

(e) Casefile/database with installation EMF survey reports, or those performed and created by USAFSAM.

(4) New Technology/Changing Equipment: The BE shop needs to always be aware of changes. Equipment can be added or upgraded by those who are not aware of equipment hazards. Periodic review of inventories is an ongoing necessity. This must occur during regular

casefile/workplace visits and/or by other requests from Installation or Unit Commanders inquiring and verifying that base emitters have been inventoried and evaluated.

c. Hazard Evaluation

(1) Hazard Code: Once the parameters for an emitter have been inventoried and recorded, the next step is to determine the hazard code. Sometimes this task is difficult to complete for BE technicians who have very little EMF experience. The major factor determining the hazard code is base on accessibility of personnel. Hazardous areas that are well above ground level or in some other way not normally accessible are labeled "IH" or "CH" and are regarded as a small concern. Sometimes only a BEE Tech, looking directly at a particular emitter, can make this determination. See Appendix A for a full listing of hazard codes. If after reviewing the list of possible codes and you can't decide which one to assign, USAFSAM can assist.

(2) Hazard Estimate: Along the same lines as determining a hazard code for a device, the BE should make a more detailed determination of the hazard potential of an emitter. Several options are available for getting the hazard estimate needed; in order of preference:

(3) Inspect the documented operating parameters of the device. An Emitter producing less than 28 W (Upper Tier) or an emitter producing less than 5.6 W (Lower Tier) exposing an average person (70 kg), will not exceed the whole-body Specific Absorption Rate (SAR) of 0.4 W/kg (Upper Tier) or 0.08 W/kg (Lower Tier). This is a "non-hazardous emitter." Exposures will not exceed the whole-body SAR as long as the cumulative power is less than the stated values. No further evaluation or data collections are required for non-hazardous emitters. Hand-held radios, cellular telephones, etc. usually fall into the non-hazardous category.

(4) Look up data from past surveys of the emitter or other emitters of the same type. USAFSAM maintains an emitter survey data base that cross references emitter data.

(a) Refer to a technical order on the system that specifies the necessary hazard information.

(b) Perform a simple MPE distance calculation on the system parameters. This estimate will be more conservative than the others, but is useful nonetheless. See Appendix H for a basic analysis. If a more detailed analysis is desired, an approved method is contained in IEEE Std C95.3-2002, Annex B.

(c) Use the available information to make an educated "guess" or consult with USAFSAM. This becomes necessary when the system parameters are not known, or when the mathematical models do not fit. This is the case with many fixed, airborne and land mobile communications systems that operate at HF, VHF, and UHF frequencies and employ thin omni-directional "linear" antennas.

(5) Survey Requirements: Once the background information on each emitter has been established and an estimation of the hazard zone for an emitter has been determined, the next step is to determine the necessity for performing a survey of the emitter. Many people automatically

equate “survey” to “take measurements.” That is not always the case. There are two types of surveys we would like to differentiate:

(a) Emitter site inspection survey: Survey of an emitter site to determine accessibility of EMF emitters to personnel, how the emitter is used, and the condition of the control measures.

(b) Measurement survey: Near and far-field calculations need to be done prior to surveying. In the event that calculations are not made prior to monitoring, special monitoring concerns will come into play when crossing from the far field and entering the near field. Separate measurements of both the electric and magnetic fields should be made until it is certain that one is well outside the near field before relying on a single probe. A single probe is used only when the electric and magnetic fields are proportional and interchangeable, that is, the ratio of the two remains constant through space (i.e. far field). Measurement surveys will be performed to determine levels of EMF in regions accessible to personnel.

(6) Performing a Site Inspection Survey: There are many important aspects to consider during a site visit. This monitoring survey, coupled with the initial hazard estimations, should allow the BE to determine if there are any potentially hazardous areas accessible to personnel. Verify there are no other EMF sources in the same area or overlapping sources. In this survey BE should evaluate existing OIs for effectiveness and evaluate any existing control measures. Take time to note the work practices of shop personnel. Sometimes actual work practices vary considerably from their description!

(7) For some of the emitters evaluated it will be necessary for you to complete a site inspection survey before determination can be made of the need for a measurement survey. The following examples are provided to illustrate the evaluation process.

Example 1. The AN/TPS-75 is a mobile rotational ground radar set designed to conduct long-range search and altitude-finding operations simultaneously. Its pulse-to-pulse frequency diversity is used to decrease vulnerability to jamming.

Recommendations: This is a transportable 3-dimensional rotational air search radar. Using the Rotating Antenna MPE Distance equation, Equation 18, the controlled hazard distance is approximately fourteen feet at 31 GHz. Reference actual survey data in a USAFSAM Report or other reliable source. If no actual survey data are available a baseline measurement survey should be performed.

Example 2. The AN/ARC-164 is a UHF radio contained on the belly of C-130 aircraft. The blade emitter operates across the frequency range of 225 to 400 MHz a power of 40 watts and an antenna gain of 3 dB. The most restrictive MPE is 61.4 V/m based on operation at 225 MHz. Using the MPE distance equation, Equation 10, the controlled hazard distance is less than 1 inch at 225 MHz.

Recommendations: Survey measurements are not necessary. This device does not continuously transmit an EMF signal so the average power during a typical transmission is a small fraction of the emitter peak output power.

Example 3. The RDR-4000 is a weather radar system located in the nose of C-17 aircraft. It operates in the low GHz range, has an average power output of 40 watts with an antenna gain of 35 dBi.

Recommendations: The RDR-4000 has a hazard distance is 14 feet (4.27 meters). It can be set up in TEST mode which allows the system transmit two 550 microsecond pulses at the beginning of the test sequence and limit the hazard distance to 0.8 inches (2.1 centimeters) from the antenna during this period. This is found directly against the nose of the aircraft. The beam shall be off when personnel work in front of the aircraft. Ensure access points are clearly marked with EMF warning signs with instructions "contact operator before accessing elevated locations that may be in the beam." Access panels should be locked.

Example 4. The AN/TPQ-43 (SEEK SCORE) is a transportable aircraft tracking radar system. During normal operation, antenna elevation is between -1.0° and +3°. The antenna height is approximately 25 feet above ground level. During maintenance, the antenna structure is lowered to a level where the antenna center is approximately 6 feet above ground level. The emitter operates between 8500-9600 MHz, has an average output power of 100 watts, and has an antenna gain of 42 dB; the antenna is circular and has a diameter of 6 feet. Using the far-field equation, the controlled hazard distance is ~116 feet at 9.6 GHz.

Recommendations: Past measurement reports recommend a hazard distance of 10 feet for maintenance, while the emitter is nonhazardous during normal operation since the main beam is inaccessible. This emitter exhibits an obvious conflict between the actual measured hazard distance and that predicted by the far-field equation. The problem with the controlled hazard distance calculation of ~116 feet is that it is still on the fringe of the near-field region that extends out to 80.5 feet from the emitter; the far-field region begins at 638 feet from the emitter. Near-field power density values calculated with the MPE distance equation are always higher than actual near-field power density.

(8) The process described above for determining the extent of survey requirements for any given emitter is not a simple process. The illustrations are provided to explain some of the logic behind the decision process; the goal of this process is to limit the amount of survey work requirements. If you researched the emitters well, most of the emitters will require no measurements.

(9) Arrange a date and time when the emitter will be available for survey and will be transmitting. Make sure that support personnel will be available to operate the system, as well as the necessary mobile lifting equipment, hand-held radios, climbing gear, etc.

(10) Verify all personnel who will be potentially exposed to EMF have the proper training per AFOSH 48-9.

(11) Check out your equipment. Is the calibration current? Does the probe frequency range cover the output frequency of the emitter being surveyed? Does the battery check meet the minimum levels? For pulsed radar systems, have you performed a probe burnout calculation? (If not, see Chapter 8, Section e).

(12) A successful survey is a safe survey that produces the necessary data and results in the understanding and satisfaction of all the key players. See to these matters before you start:

(a) Conduct a complete and proper briefing of all personnel involved explaining the survey. The unit POC and AF System Safety officer (AF/SE) should be notified of any survey work being performed in their workplace.

(b) Ensure that adequate communication is provided between the operators of the emitter and the survey personnel. Be sure that absolute control over the emitter output is established and maintained during measurements. You would be surprised how many accidental exposures have occurred trying to survey EMF emitters.

(c) Always begin the survey at a distance greater than the estimated MPE distance, with the meter on its maximum range setting.

(d) The exact procedures you will follow as you set-up and perform your survey will vary somewhat for different emitter types. Detailed notes on surveying ground mounted EMF emitters are given in Appendix C, airborne EMF emitter: in Appendix D, and non-antennae field generating devices in Appendix E. An EMF Survey Checklist is provided in Appendix F.

(e) Explain your findings from the site and/or measurement survey as best you can to the workplace supervisor, BE, and other key personnel in the workplace. Don't surprise them later with unexpected requirements. Let them know about anything that could affect their operation.

(13) Frequency and extent of workplace visits. Once a baseline survey is accomplished for all emitters with hazard potential, follow-up workplace visits should be scheduled. For the most part, unless there are significant changes to the EMF output of the emitter, survey measurements need be performed only once. Follow-up visits usually include evaluation of OIs and existing control measures, observation of any changes from the previous survey, and shall include EMF education (BE personnel will coordinate with Public Health as needed). The frequency of these visits is dependent on the emitter. For most emitters an annual workplace visit will be sufficient. Where the emitter may be directed into areas accessible to personnel or other more hazardous scenarios, quarterly or biannual visits may be more appropriate. Individual installations shall set their rate of occurrence.

d. Control Measures

(1) General: Once survey work is complete, the next step is to determine necessary control measures and/or evaluate existing control measures. For emitters that are nonhazardous or have hazard zones that are inaccessible, there is no requirement for any control measures. For emitters that create accessible hazard zones, the following paragraphs will assist in determining what control measures are required.

(2) Administrative Controls: Below is a list of administrative control measures. In no way is this list meant to be totally inclusive.

(a) Radio Frequency Radiation/EMF Warning Signs: When verifying the compliance of existing signs, they should conform to established specifications, such as those contained in the most current IEEE C95.2 standards and ANSI Z535.2-2007 and Z535.4-2007 relative to use of symbols, colors, text fonts and sizes, using signal words as indicated herein. Danger signs should be reserved for imminently hazardous circumstances. Warning signs shall be posted for potentially hazardous circumstances. Caution signs shall be posted at all access points to areas in which levels exceed the Upper Tier environment MPEs. Notice signs shall be posted where the EMF levels exceed the Lower Tier MPEs.

(b) Cones with Notice, Caution, Warning or Danger Signs Affixed: Simple orange/yellow traffic cones with an affixed EMF warning sign.

(c) Roped Off Areas with Notice, Caution, Warning or Danger Signs: Temporary or permanent. A temporary area may implement wooden stands that are attached to each other with rope. A permanent area may implement wooden or metal posts. In either case, signs should be attached to the posts or rope.

(d) Flashing Lights or Audible Signals: Used in areas with high energy EMF emitters.

(3) Engineering Controls: Below is a list of engineering control measures. In no way is this list meant to be totally inclusive.

(a) Fences: Metal chain link fences or wooden fences. HF emitters are commonly surrounded by wooden fences, because metal fences may passively reradiate EMF.

(b) Azimuth Blanking: A common practice for aircraft search radar. Azimuth blanking allows operators to null transmissions when the radar is pointed at a particular range of azimuths or mechanically (or electronically) restrict the radar from pointing in a certain azimuth. Normally this is implemented to prevent ground structures from interfering with the radar, but it can also be used to prevent EMF hazards to personnel. Caution—be sure this control measure is being implemented; some systems allow azimuth blanking to be enabled (or disabled) by simple updates on a computer terminal.

(c) Dummy Load: Dummy loads are used by maintenance groups to allow transmitter operation while blocking of the free-space EMF wave propagation. A dummy load is typically a resistor connected up to the transmission line in place of the antenna; absorbing the transmitter output power.

(d) Interlock. Device that prohibits operation of an emitter when a door, hatch, or other entry point is breached.

(e) Barriers. Rope, chain, or other barrier across access to stairs, walkway, etc.

(4) Specific Examples: The following examples are provided to illustrate the application of control measures.

Example 1. Given: An aircraft tracking radar is located on the roof of a building. The radar has a main beam controlled hazard distance of 100 m; the main beam is accessible from the roof but not at ground level. Seldom are personnel required to access the roof.

Recommended controls: Locate EMF warning signs at all access points to the roof; the signs should contain additional text stating, “Access to Roof Restricted, contact radar operators before gaining access.”Additionally, it is recommended to put a chain across any stairs or walkways that lead to the roof.

Example 2. Given: A VHF base communication antenna is located on the top of a roof. The antenna has a 3 m controlled hazard distance. Personnel routinely access the roof.

Recommended controls: Rope off the hazard area and post EMF warning signs.

Example 3. Given: The B-1B Defensive Avionics, AN/ALQ-161, in a multiple antenna radar system. The system has a controlled hazard distance of 7 feet from any antenna, but is not a ground hazard since the aircraft is 4 m above ground level.

Recommended controls: Place cones beneath all AN/ALQ-161 antennas. Place warning signs on cones with additional text stating: “EMF hazards for personnel on ladders or platforms.”

Example 4. Given: AN/FPS-115, PAVE PAWS phased-array search and track radar has a calculated controlled hazard distance of approximately 7,772 m in front of both antenna faces. The array faces are tilted back 20 degrees to allow for an elevation deflection from three to 85 degrees above the horizon. The upward focus of the EMF energy limits the ground hazard controlled area distance to less than 60 meters. This is verified by site surveying.

Recommended controls: Place permanent poles blocking access to the controlled area distance in front of each antenna face and connect poles with chain or rope. Place warning signs on poles or rope. The radar is enclosed by two barbed wire security fences around the perimeter; access to the ground region in front of the radar is limited to authorized personnel. Limit future elevated work that may enter the focused EMF field above the perimeter boundaries.

Example 5. Given: An avionics maintenance function performs maintenance on aircraft radar transmitters. A radar system being worked on and in use has a hazard distance of 15 m without a dummy load and 0 m with a dummy load.

Recommended controls: Place warning signs at the entrance to the workplace and in the vicinity of every transmitter repair work station. Dummy loads should be used for all test sets.

e. Documentation: After the site visit, analyze your data and formulate your final conclusions and recommendations.

(1) Prepare a report and send a copy to the supervisor owning the EMF source. File your data notes, photographs, drawings, correspondence, etc., for future reference in the case file.

(2) Where a new EMF/RF emitter has been added to an installation, it will be necessary to complete the steps in DOEHRS for entering a new RF Emitter into the shop inventory and completing the corresponding steps in DOEHRS for an RF Survey. Follow all the steps noted in Appendix A of this guide.

Where a new EMF/RF emitter has been added to an installation: send the emitter parameters into USAFSAM through the ESOH Service Center for inclusion into the Radio Frequency Emitter Inventory **esoh.service.center@wpafb.af.mil**.

(3) AF 2759 Forms can still be used to keep handwritten field notes of case file EMF data, but should not be considered the primary record. The DOEHRS data is the primary record. The 2759 can also be scanned and kept as an attachment in DOEHRS.

8. Instrumentation

a. General: Several commercially available instruments permit direct broadband field strength measurements. The BE member should be familiar with the operation and limitations of the equipment as provided by the manufacturer. All field strength and current measurements should be performed in accordance with established standards such as IEEE Std C95.3 or equivalent. It should be noted that erroneous EMF assessments could result when equipment is used in environments for which it has not been tested. This is commonly true for EMF probes used in moderate to high strength 60-Hz electric fields, e.g., near electric power lines.

b. Instrument Design and Operation Principles: If using Narda equipment, the electric field probes use a series of dipoles, while their magnetic field probes use a series of coils to measure induced current. These elements absorb and dissipate energy into thin-film thermocouple elements or diodes.

(1) Diodes are widely used since they are sensitive and can also tolerate relatively higher field strengths without suffering overload. They are being used more often in newer equipment models than thermocouple elements. By using diodes instead of thermocouples, it is possible to handle a much wider field strength dynamic range of typically 60 dB. Diodes are non-linear devices and in weak fields they produce a rectified voltage proportional to the square of the incident field strength. In stronger fields, diodes operate out of the square-law region and processing electronics are required to compensate for the deviation, and can affect the accuracy of measurements of time-averaged field strength when the fields are pulse modulated. Another potential source of error is the sensitivity of diodes to temperature variation. Diodes must be enclosed by optically opaque material in order to avoid photovoltaic effects.

(2) Thermocouples detect temperature changes and produce a rectified voltage proportional to the power deposited in the junctions of the device. Since EMF power is proportional to the square of field strength, thermocouples operate as true square-law devices in EMF fields. This characteristic means thermocouple detectors are well adapted for measurements under conditions of multiple frequency and for evaluating the time- averaged strength of pulsed fields. Disadvantages of thermocouples include thermal drift, limited dynamic range, susceptibility to burnout in strong fields and their relative insensitivity.

c. Calibration: Instruments used for exposure assessment shall be calibrated and validated to confirm that the instrument is operating correctly with appropriate documentation. Recalibration shall be performed per the manufacturers' recommendations. Instruments that have been dropped, damaged, repaired or modified, or show signs of erratic behavior/operation should be recalibrated. Instruments that has exceeded its regular calibration cycle should not be used for assessments unless in response to an urgent exposure request. A post-calibration of the instrument would then be acceptable. In this case, the response of the instrument before adjustments are made in the calibration process should be noted so that the previous measurements can be appropriately corrected. In some instances, comparison of instrument readings with those of another instrument can be useful in judging the consistency of measurements.

d. Correction Factors: Narda probes are calibrated at many discreet frequencies. Probe correction factors are printed on the probe handle for different frequency points. If the particular emitter frequency is between two values, a correction value can be calculated by linear interpolation of the other two values. As an example, suppose one is measuring an emitter that operates at 4000 MHz and the probe correction factors for 3000 MHz and 5000 MHz are 0.9 and 0.95, respectively. Then, appropriate correction factor for 4000 MHz is 0.925. Correction factors are multiplied by the meter reading to obtain actual power density.

e. Probe Burnout: The thin-film thermocouples are very sensitive elements that are susceptible to probe overload or burnout when exposed to very high power density fields. It is important to note that the probes are susceptible to burnout even if the meter is off or if the probe is disconnected. The maximum peak and average power densities the probe can withstand before burnout occurs are normally printed on the handle of the Narda probes. The burnout characteristic is typically 3 times full scale in terms of average values. Newer designs of thermocouple instruments have burnout ratings of 15-20 times full scale. Thin resistive films provide very broad bandwidth. Probe burnout is not a real problem in making measurements of CW emissions because the probe burnout threshold is significantly higher than the maximum possible meter reading; as long as the surveyor is watching the meter and does not allow it to exceed a full scale deflection, one does not risk probe burnout.

However, levels high enough to cause probe burnout are possible when making measurements of pulsed EMF signals with very short duty factors even at meter deflections less than the MPE and the full scale deflection value of the meter. In this case, the average transmitted power may be very low while the peak power is very high. If the peak power absorbed by the probe exceeds the peak overload value, the probe will fail even though the average power indicated by the meter is indicating a value less than full scale. See Figures 17 a and b for a graphic description of this phenomena. Figure 17a illustrates an emission with a short duty factor; note the low average power represented by the dashed line. Figure 17b illustrates an emission with a long duty factor; note that even though the peak power in this case is less than that of Figure 17a, the average power is considerably larger.

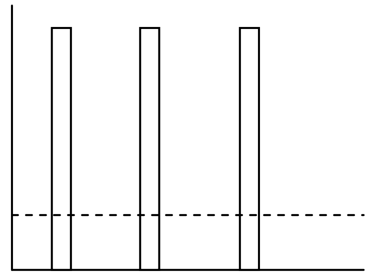


Figure 17a. Short Duty Factor

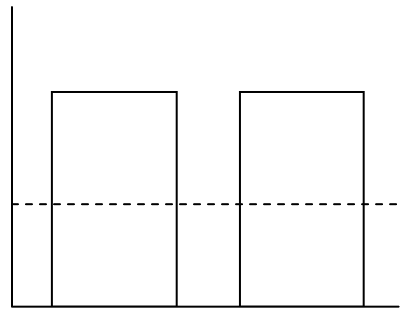


Figure 17b. Long Duty Factor

The following equation, if used, can prevent a costly accident and a red face!

$$PD_{max} = DF \times BR / CF$$

Equation 15. Electrostimulation Far-Field Boundary Calculation

Where: PD_{max} = Maximum meter reading before burnout
DF = Duty Factor (DF = PW x PRF)
BR = Burnout Rating (Peak Power Density Rating)

<u>Example Burnout Ratings for Narda Equipment</u>
White Handle Probes (8731, 8741,) = 6×10^4 (Overload value – 20 mW/cm^2 or 200 W/m^2)
Brown Handle Probes (8623, 8752) = 3×10^5 (Overload value – 200 mW/cm^2 or 2 kW/m^2)
CF = Correction Factor (Printed on probe handle for frequency of operation)

If PD_{max} is greater than full scale there is no cause for concern provided the surveyor does not exceed full scale. On the other hand, if PD_{max} is less than full scale reading, the surveyor must monitor the meter at all times. If the meter reading exceeds PD_{max}, even briefly, probe burnout is risked. Note these examples:
Example 1: PW = 2 μs, PRF = 360, DF = 0.00072, CF = 1

PD_{max} = [.00072 x 300000 (8623 probe)]/1 = 216 mW/cm^2 (or 2160 W/m^2 or 2.16 kW/m^2)

Conclusion: Low risk of probe burnout since 216 mW/cm^2 is greater than full scale of 100 mW/cm^2 or $1kW/cm^2$ (8623 probe)

Example 2:   PW = 0.25 μs, PRF = 800, DF = 0.0002, CF = 1

PDmax = [0.0002 x 300000 (8623 probe)] = 60 mW/cm^2 (or 600 W/cm^2)

Conclusion: High risk of probe burnout since 60 mW/cm^2 is less than full scale of 100 mW/cm^2 (8623 probe).

The inability to zero an instrument is a telltale sign of a possible probe burnout. Test the probe cable for a possible wire break, since this condition can exhibit a like effect. High-intensity field areas (e.g. the main beam of a directional antenna) should be approached from a distance to avoid probe burnout. The surveyor then gradually proceeds to move progressively closer to the regions of higher field strength. Extreme care must be exercised to avoid overexposure of the surveyor and survey instrument.

f. Zero Drift: Zero drift is inherent with instrumentation that utilizes thermocouples and temperature sensitive components. Premature commencement of a survey without allowing the electronics to reach equilibrium and a change in ambient temperature during a survey are common causes of zero drift. To reduce errors from zero drift, we recommend:

(1) Connect and turn instrumentation "on" at least 10 minutes before survey measurements are made. Locate instruments in the same environment you intend to survey; it doesn't make much sense to equilibrate instrumentation indoors if one intends to survey outdoors at a different temperature.

(2) Periodically check the zero of an instrument during survey measurements, especially in one is moving between areas of significantly different ambient temperatures (sunny vs. shaded). To re-zero instrumentation during a survey one can:

(a) Completely leave the EMF field.

(b) Completely shield the probe in a metal can or Narda instrument case if it provides shielding.

(c) Shield the probe with your body. Your body will effectively absorb signals with frequencies higher than 1,000 MHz.

g. Out of Band Response: Potential measurement errors can occur when using a probe outside of its frequency range. Although this problem can occur with all probes, it is more marked in magnetic field probes due to periodic resonances above their rated band specification. If a signal coincides with an out of band resonance frequency of the probe, a high false meter indication may result. Electric field probes typically give a low false meter indication since resistive dipoles result in very dampened resonances. Only use probes that have been calibrated and fully cover the emitter frequency range.

h. EMF Interference: As noted earlier, this can become a significant problem at lower frequencies, since it is more difficult to shield readout electronics and cables at frequencies ≤500 MHz. As a field test for this problem is to completely shield and ground the sensor tip of an electric-field probe with metal foil. This test allows the determination of the existence of EMF interference or “capacitive coupling” between the cable and readout and nearby radiating objects during the measurement. Fiber-optic cables, high-resistance cables, double-shielded coaxial and signal cables can be used to connect EMF survey instruments to the probe to minimize the effects of EMF interference.

i. Types of Meters:

(1) Electric and Magnetic Field Strength Meters: Electric and magnetic field strength meters are narrowband devices. Examples of these Narda meters are noted below in Figure 18a. All the 8700 series meters have interchangeable probes for electric and magnetic fields. They consist of an antenna, cable(s) to carry the signal from the antenna, and a signal conditioning/readout instrument. Narda’s newest broadband field meters plug-and-play probe interface with automatic probe parameter detection (see Figure 18b).

Field strength meters may use linear antennas, such as monopoles, dipoles, loops, biconical or conical log spiral antennas, horns or parabolic reflectors. The appropriate field parameters can be determined from a measurement of voltage or power at the selected frequency and at the antenna terminal. The electric (or magnetic) field strength can be derived from information on the antenna gain or antenna factor and the loss in the connecting cable.

Figure 18a. Narda 8711 Survey Meter with Narda 8723D and 8733D Probes

Figure 18b. Narda NBM-520 Survey Meters and Probes EF3091 & EF3061

(2) Induced Current Meters: Induced current meters display the amount of current induced through the body to ground when an individual is standing in an electric field created by a high-power transmitter. These currents can provide an indication of energy absorbed by the body. Induced current meters are generally stand-on devices that measure the induced current flowing through the subject's feet to ground. The stand-on baseplate (see Figure 19) is made of two stainless steel plates and is, in fact a capacitor/resistor network. The meter reads the current flowing through the resistor connected between the capacitor plates. The size of the baseplate is kept small to minimize any pick-up of electric field from the sides of the baseplate. There are also the clamp-on induced current meters that can measure directly the induced current in arms and legs using clamp-on sensors (see Figure 19). Typical frequency range of commercial meters is from 10 kHz to 100 MHz.

Figure 19. Induced Current Meters: a Holaday Hl-3701 induced current meter and an induced current transformer HI-3702, clamped around the ankle and

(3) Contact Current Meters: Contact current meters display the amount of current through the body caused by contact with a 'hot' metallic object located in the vicinity of a high-power transmitter. These meters generally feature an insulated contact probe for contact with the 'hot' object. Together with a stainless steel baseplate and internal circuitries, the measured current simulates the equivalent induced current by a barefoot individual gripping the 'hot' metallic object. These measurements can be made with a simple multimeter like the one in Figure 20.

Figure 20. Contact Current Meter: Fluke 170 Multimeter being used to test for mA levels of contact current

(4) Magnetic Field Measurement Meters: Many sources (devices) produce static magnetic fields. Static magnetic fields result from either fixed magnets or magnetic flux radiating from the flow of direct current (DC). See Section Chapter 5 for exposure limits on sub-radio frequency magnetic fields. Sources producing these fields include (but are not limited to) the following: Nuclear Magnetic Resonance (NMR) imaging and spectroscopy devices, Electron Paramagnetic Resonance (EPR, ESR, EMR) devices, or Helmholtz Coils, Solenoids, DC Motors, etc. NMR magnets commonly produce core fields from 0.2 T to 20 T. These fields decrease in intensity as the distance from the core increases. A field strength map of the area surrounding the magnet should be developed by the BE staff, based on measurements by instruments like the one in Figure 21, and posted for use by equipment owners. BE staff must be informed of new equipment entering installation in order to take exposure measurements with the appropriate equipment. Gauss or Tesla meters can effectively evaluate the active field strength.

Figure 21. FW Bell 5180 Gauss Meter

j. USAFSAM Assistance Requests: Installations can request assistance from USAFSAM/OE by contacting the ESOH Service Center. When requested, the USAFSAM/OE group can provide sampling equipment.

ESOH Service Center
DSN 798-3764
Com 937-938-3764
Toll Free 1-888-232-ESOH (3764)
Website: **https://kx.afms.mil/esoh**
USAFSAM Consulting E-mail: **esoh.service.center@wpafb.af.mil**

9. The EMF Accident/Incident

a. I've Been Zapped!

(1) When the subject of an EMF accident/incident comes up at your base, there is one fundamental question that must be answered before you proceed. Is the person involved curious about their work area being hazardous or is the person saying, "I've been overexposed!?" Before an investigation takes place someone must make an allegation. Even though someone swears they've been overexposed, it may not be necessarily true. On the other hand, if someone says it happened, there's no recourse but to investigate the incident.

On the flip side, someone may not know or think they've been overexposed unless the BE group is alerted of possible accidental exposures and back-calculates based on the estimated time in the exposure area. They must determine the probable exposure amount in comparison to the MPE. This type of incident case must also be investigated by the installation BE group.

Regardless of whether the possible exposure is self reported, reported by others or calculated by worker monitoring that somehow exceeds time limits and/or planned work boundaries; the incident MUST be reported the ESOH Service Center at **https://kx.afms.mil/esoh /** or 1-800-473-3549 or DSN: 798-3764. Complete and send in a DoD Tri-Service EMF accident/incident reporting form, per DoDI 6055.11 and AFOSH Std 48-9.

(2) The benefits of a good EMF emitter inventory and baseline survey will show through during a suspected overexposure incident. If Bioenvironmental Engineering (BE) has a thorough inventory and baseline on all potentially hazardous emitters, Public Health should be able to make an initial determination of exposure received to individuals once the workplace supervisor calls with initial data. In fact, from our experience, a majority of the incidents reported to us had absolutely no potential for overexposure and could have been resolved by a telephone conversation between the BE and the reporting workplace if the BE had good documentation in their case file. Even in these cases, it is good practice to make a site visit at the minimum. In the majority of past cases, the individuals reported no symptoms and their claims were likely based on confusion and fear; ultimately the lack of EMF education.

b. Who Does What?

(1) There is a precise set of steps to follow per AFOSH 48-9 and DoD 6055.11.

(2) The installation BE group shall perform their own investigation. USAFSAM will assist in any capacity needed to complete the investigation. It can normally be done by a telephone or email consultation. If it is determined that the BEE does not have the ability to perform the investigation, USAFSAM is abloe to assist in the investigation of the incident; all requests for our assistance must be forwarded through your major MAJCOM BE. For PACAF bases, please contact USAFSAM DET 3 first.

(3) Where investigations determine that personnel are found to be exposed at levels 5 times the MPE value, they must:

(a) Perform field EMF measurements at the location for documentation of the EMF exposure. This is done to verify actual levels which can often be less the calculated levels.

(b) Receive a medical examination and recommendations for medical follow-up. Public Health personnel will complete the AF FORM 190 and the EMF Overexposure Medical Format forms found in Appendix J of this Guide. These forms are also available through USAFSAM ESOH Service Center.

(c) Documentation must be provided with a description of the circumstances surrounding the exposure incident, statements from personnel involved in that incident, and recommendations to prevent similar occurrences.

(d) If desired, call EMF Hotline at 1-888-232-ESOH (3764), and discuss the incident with USAFSAM. They can help insure that there are no steps overlooked and advise you on how to proceed.

(4) The Investigation and Accident/Incident Reconstruction

(a) Take care to protect yourself and your instrument while reconstructing the incident. Make measurements with the system set up, as nearly as possible, as it was when the incident occurred. It may be that the power density at the point of exposure is greater than the measuring capability of your instrument (Narda 8723D, Max Scale= 100 mW/cm^2). If this is the case, you should make multiple measurements starting at, say, 10 mW/cm^2 and move up in increments until you reach the limit. These data can be plotted on a spreadsheet and the actual exposure value can be estimated by extrapolation. Also, USAFSAM has Narda 8715 probes that allow measurements up to 2000 mW/cm^2. These probes are being phased out, Narda's newest probes, part of the NBM Series, will similarly allow measurements up to 1500 mW/cm^2.

(b) When determining the total exposure, you must know the duration of the exposure. This can be very tricky, because the time estimates of the exposee and witnesses can be and are usually very exaggerated. Ask the exposee to repeat his/her actions and use a stop watch to get a better idea of the actual exposure time. The shorter the time, the more important this becomes.

(c) Photographs are a very important part of your investigation. With the transmitter shut down, ask everyone to position themselves exactly as they were during the incident. Then take photographs from a few different angles. You can have the base photo lab do the photography, but you must tell them exactly what you want.

(d) Crucial Documentation. In your report, BE should detail the case as far as what happened, to whom, when, and where. You should tell what you did, how you did it, that you concluded, and what follow-up action you recommend. All this must be completed in 30 days! BE provides the report to supervision owning the EMF source and AF/SE, who then have <5 days to summarize the entire investigation (see AFOSH Std 48-9 for report requirements) and distribute it.

(e) You should have a calming influence on those around you. Don’t show surprise at a high level reading or give your suppositions about the medical implications of the exposure. Avoid actions that only result in fanning the flames of a fire. Some people tend to think and expect the worst. Your bearing and aptitude will go a long way to relieve anxieties and calm fears. Be frank, open, confident, and reassuring.

Appendix A

DOEHRS EMF Hazard Survey Entries

a. The Defense Occupational Environmental and Health Readiness System (DOEHRS) is the web-based occupational exposure application deployed throughout the Department of Defense. DOEHRS manages occupational and environmental health readiness data and actively tracks chemical, physical, and biological hazards for the Department of Defense Military Health System. DOEHRS maintains longitudinal exposure records for DoD employees based on individual and grouped exposures. The URL for the DOEHRS Production application is **https://doehrs-ih.csd.disa.mil/**

DOEHRS includes non-ionizing radiation and EMF and enables authorized users the ability to document all types of radiation surveys. These surveys are then compared to the guidelines below for potential risks that are physical in nature.

b. Adding Surveys

(1) <u>Radiation surveys in DOEHRS consists of the following survey types</u>: Administrative Data, Exposure Investigation, Inventory – Laser, Inventory – Radioactive Material, Inventory – RF Emitter, Inventory – X-Ray, Laser Hazard, RF Hazard, Radiation, X-Ray.

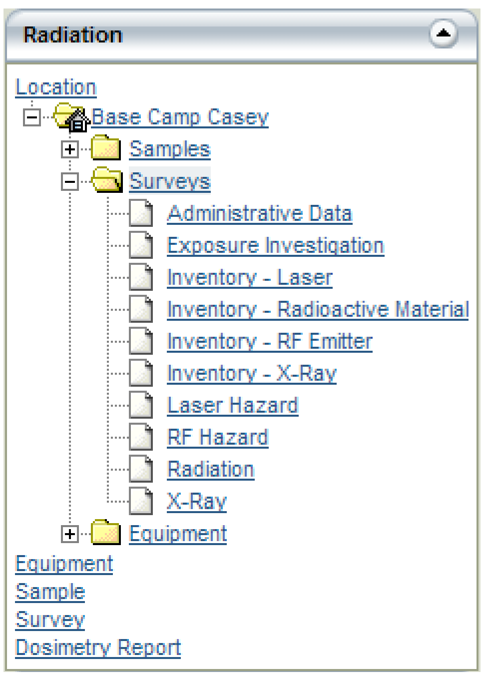


Figure A-1. Radiation Menu

(2) By selecting the Surveys option under a location in the Radiation menu, all surveys in progress, ready for QA review, and/or approved by QA will display.

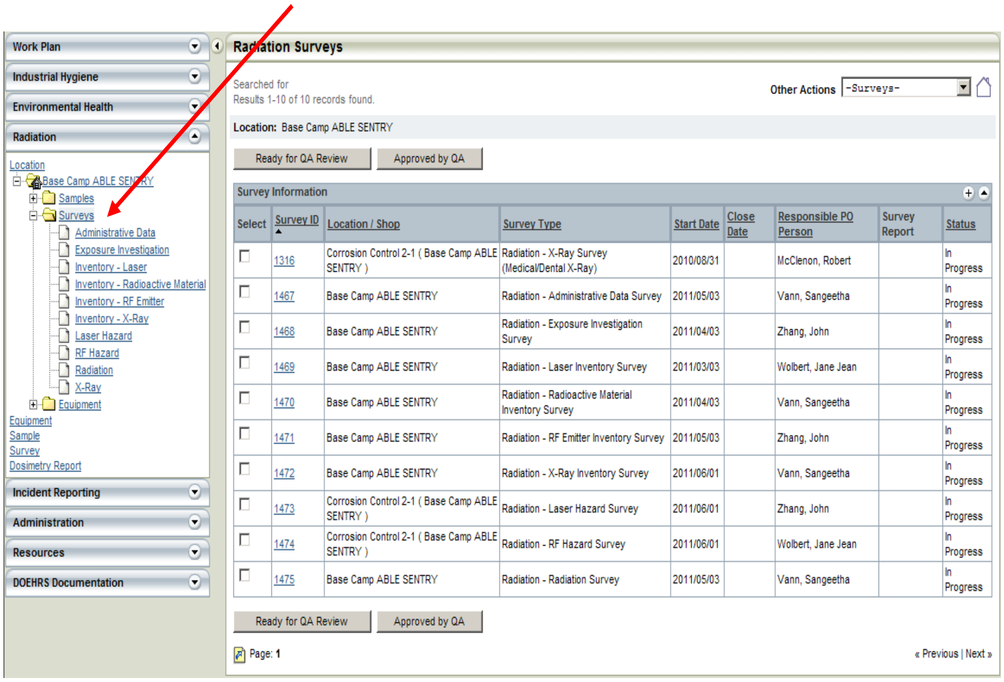


Figure A-2. Radiation Surveys

(3) These surveys can be initially created in the Master Schedule area of the application under the Work Plan menu. In the Master Schedule, the user can Save and Begin the survey after the task is created, or the item will appear in the workbasket if the item has a suspense for a later date. Surveys can also be created by selecting the plus icon on the Radiation Surveys tile or by selecting Add Survey from the Other Actions pick-list.

c. Inventory-RF Emitter Section

(1) The RF Emitter Inventory page is reached by clicking the Inventory-RF Emitter link in the navigation tree located under Radiation > Location > Surveys > Inventory-RF Emitter.

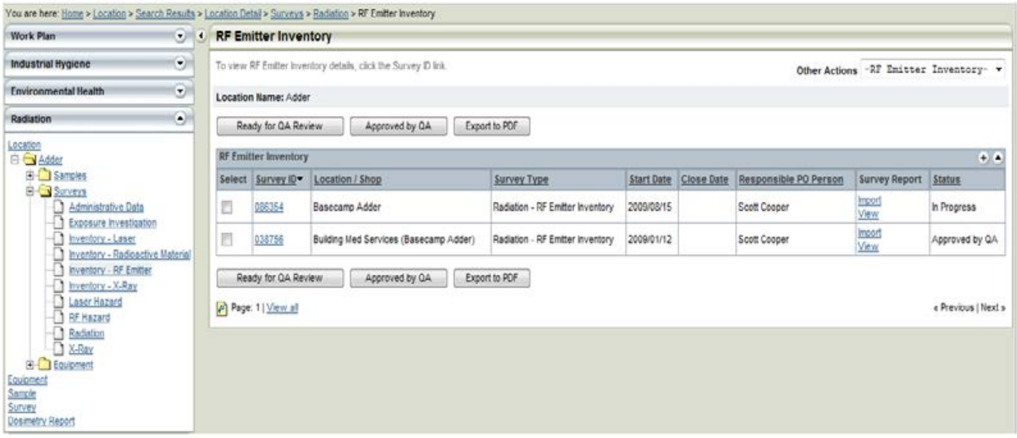


Figure A-3. RF Emitter Inventory

(2) To add a RF Emitter Inventory item. Users must select the plus icon on the RF Emitter Inventory tile. An RF Emitter Inventory – Detail page will appear and the user can document the Nomenclature and additional information as needed.

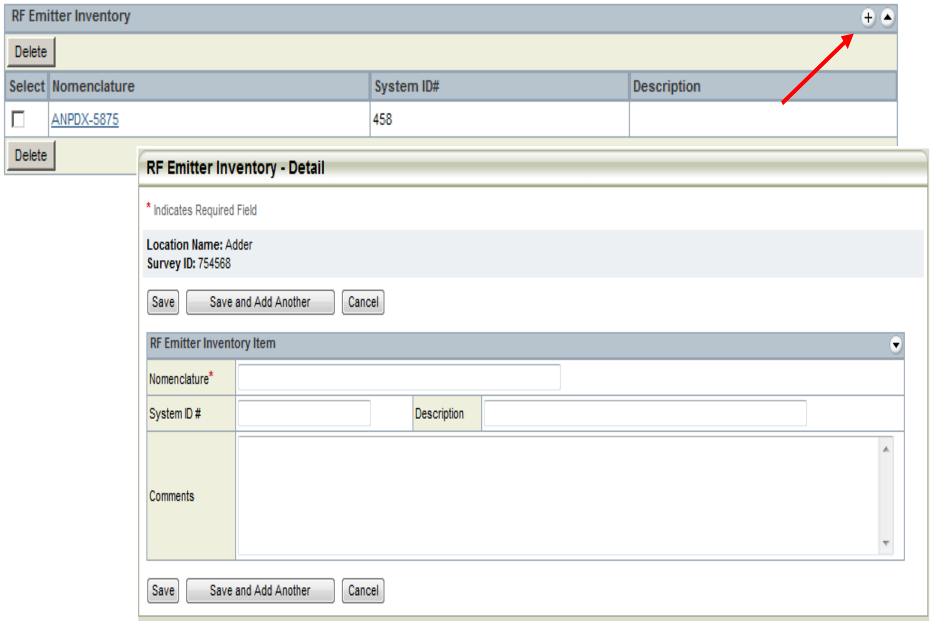


Figure A-4. RF Emitter Inventory – Detail

d. RF Hazard Entries

(1) The RF Hazard survey section in DOEHRS allows authorized personnel to perform and document a comprehensive survey of all RF Hazard systems for both occupational and environmental locations within the program office. The RF Hazard Surveys page is reached by clicking the RF Hazard link in the navigation tree located under Radiation > Location > Surveys > RF Hazard. On the RF Hazard Surveys tile the user can select the plus icon to add another survey.

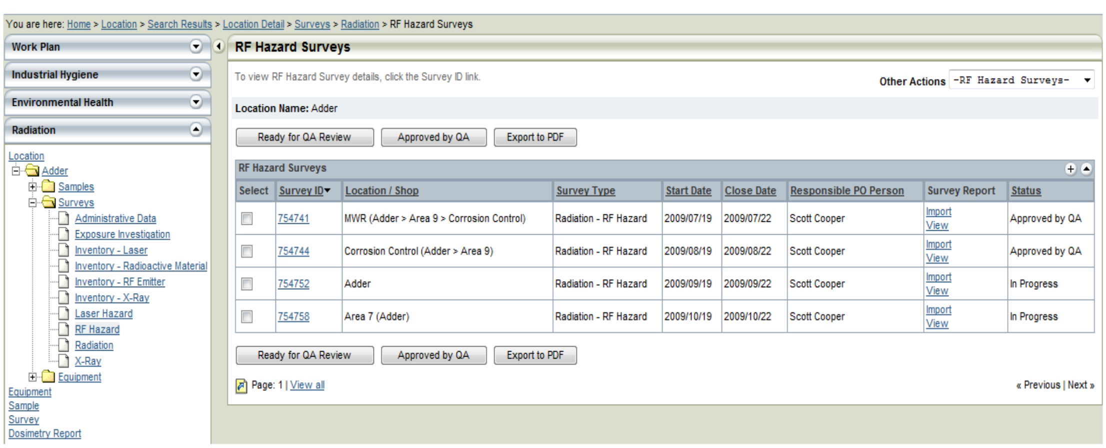


Figure A-5. RF Hazard Surveys

(2) The RF System Description tile is populated with all of the Equipment details that have already been added and are associated to the Shop and/or the Location. Note: only a portion of the RF System Description tile is displayed.

RF System Description			
System ID #	847234547	System Name	Low Density RCL
Description	Low Density RCL	Quantity of Similar Systems	3
Current Shop Assignment	Corrosion Control (F00165)	Location	MWR (Adder > Bldg 2030)
Frequency - Low	300 MHz	Frequency - High	400 MHz
Peak Power	1500 watts	Pulse Width	55 µSec
Pulse Repetition Rate	75 Hz		
Antennas			
Antenna Type	Blade		
Antenna Dimensions	xxx	Antenna Gain	xxx dB
Antenna Beam Width - Horizontal	xxx degrees	Antenna Beam Width - Vertical	xxx degrees
Beam Scan Type	Fixed Antenna	Rotating Beam Scan Rate (Rotating 360 Degrees Beam Scan Only)	xxx RPM
Scanned Sector Width - Horizontal (Sector Scan Electronic or Mechanical Beam Scan Only)	xxx degrees	Scanned Sector Width - Vertical (Sector Scan Electronic or Mechanical Beam Scan Only)	xxx degrees
Scan Rate - Horizontal (Sector Scan Electronic or Mechanical Beam Scan Only)	xxx RPM	Scan Rate - Vertical (Sector Scan Electronic or Mechanical Beam Scan Only)	xxx RPM
Antenna Type	Helix		
Antenna Dimensions	xxx	Antenna Gain	xxx dB
Antenna Beam Width - Horizontal	xxx degrees	Antenna Beam Width - Vertical	xxx degrees
Beam Scan Type	Rotating 360 Degrees	Rotating Beam Scan Rate (Rotating 360 Degrees Beam Scan Only)	xxx RPM
Scanned Sector Width - Horizontal (Sector Scan Electronic or Mechanical Beam Scan Only)	xxx degrees	Scanned Sector Width - Vertical (Sector Scan Electronic or Mechanical Beam Scan Only)	xxx degrees

Figure A-6. RF System Description

(3) The Measurement tile allows the user to enter Meter and Probe Serial/Model #'s and Hazard Distance Measurements**.**

Measurements			
Meter Serial #/Model #		Probe Serial #/Model #	
Hazard Distance Measurements	Upper Tier - Whole Body		
	Upper Tier - Local Body Exposure		
	Lower Tier - Whole Body		
	Lower Tier - Local Body Exposure		

Figure A-7. Measurements

(4) The Hazards Control Data tile allows the user to select appropriate check box next to any Hazard Control Code(s) listed.

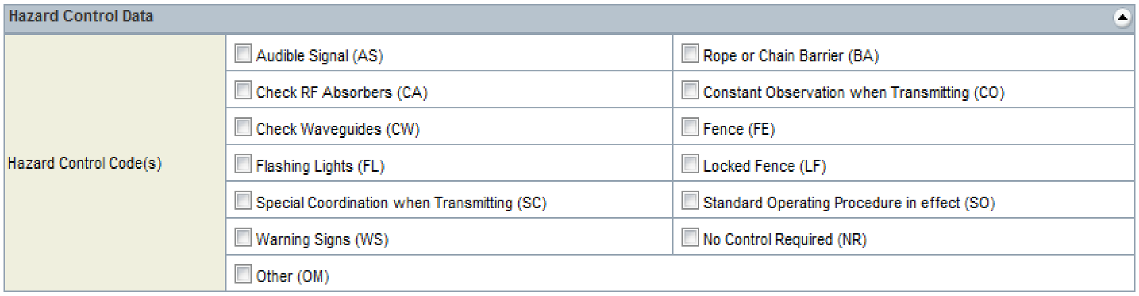


Figure A-8. Hazard Control Data

(5) The Periodic Checks tile allows the user to answer quick yes/no questions and enter any observations noted at the time of the survey.

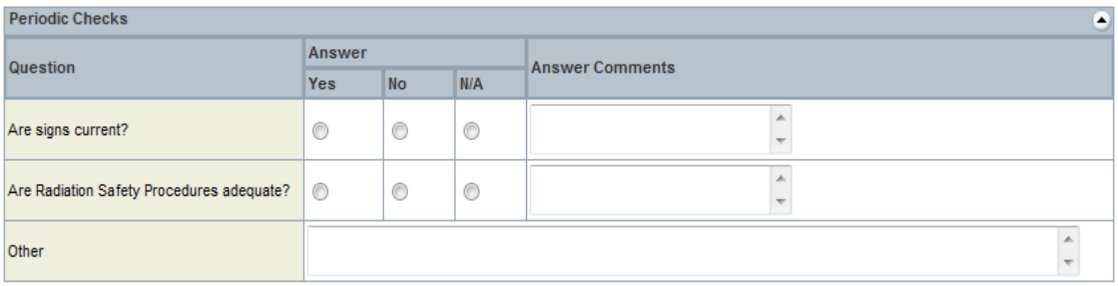


Figure A-9. Periodic Checks

(6) The Calculations tile allows the user to enter any applicable calculations information and notes, free text style, to the field.

Figure A-10. Calculations

Note: Static magnetic field measurements, induced and contact current measurements will have to be added in the Calculations field as there is no other fields presently available to put these measurements.

e. Acronym Use Options. The following acronym codes can be used in DOEHRS to identify items where field space is limited:

(1) Antenna Code: The following codes to identify the type of antenna observed:

BL—Blade (or fin)
CR—Circular Reflector
DC—Discone
DI— Discage
DL—Dummy Load
DP—Dipole or Dipole Array
HC—Horn (plane, conical or biconical)
HE—Helix (helical)
HL—Horizontal Log Periodic
LE—Lens
LO—Loop
LW—Long Wire
MO—Monopole or Colinear Array
OD—Other Directional
OO—Other Omnidirectional
PA—Phased Array
RH—Rhombic (or V)
RR—Rectangular Reflector
SL— Slots/Slot Array
SP— Spiral
ST— Stub
VL—Vertical Log Periodic
WA—Waveguide Array (slot/hole)
WH—Whip (or long wire)
YA—Yagi or Yagi Array

(2) Scanning Code: Use one or more of the following to describe the motion of the antenna beam:

F—Fixed
R—Rotating, 360 degrees
T—Tracker*
S—Sector Scan (Mechanical)*
E—Sector Scan (Electronic)*
*Note: If S or E is entered, also enter the width in degrees of the scanned sector.

(3) Estimated Hazard Distance: The estimated hazard distance in feet theoretically derived. Indicate one of the following in parenthesis in addition to the numerical distance:

F—Far Field
T—Extracted for manufacturer's data sheet
N—Near Field Correction Applied
O—Other source noted

(4) Hazard Code: The following codes can help to describe the hazard category into which this emitter falls:

NH—No levels generated in excess of the MPE.
IH —Hazardous levels possible, but in normally inaccessible areas.
CH—Hazardous levels possible, but only in areas that require climbing.
GH—Ground-level hazardous exposures possible.
DL—Transmitter dummy loaded.
SH—Hazardous levels possible, but transmission time is too short for overexposure.
OD—Other device (non-antenna); no levels generated in excess of the MPE.

OE—(non-antenna); levels generated in excess of the MPE.

(5) Hazard Control Code: The following codes can help to describe the recommended controls for this system:

AS—Audible signal
BA—Rope or chain barrier
BL—Blanking
CO—Constant observation when transmitting
FE—Fence
FL—Flashing light
IN—Interlock
LF—Locked fence
NR—No control required
OM—Other (please describe)
SC—Special coordination when transmitting
SO—Standard operating procedure in effect
WS—Warning signs

Appendix B

EMF Emitter Survey Database

The following is an example of some airborne EMF emitters found with the Air Force USAFSAM emitter database. It is expected that BE personnel add this data (and other data columns not shown below) as emitters are added to their installation. When changes occur to this equipment or as MPE values change and affect hazard distances; the data must be updated. Notices must also be sent in to USAFSAM when emitters should be removed; when they are no longer found at the installation. Most emitters in the Air Force inventory have multiple configurations (i.e., different antennae, waveguides, or power levels) possible depending on the deployment platform. There is also seen a wide variety of local modifications (mostly of ground based emitters). Any modification of the emitter is likely to change the accessible radiation levels, the hazard distance, or the necessary controls.

NOMENCLATURE: The nomenclature of the emitter. Most nomenclatures are standard AN nomenclatures (we left the AN/ off). See the 2nd note below for more explanation.
FREQ_MIN: Minimum emitter frequency in megahertz (MHz)
FREQ_MAX: Maximum emitter frequency in megahertz (MHz)
EMITTER_DESCRIPTION: Other trade name or description to identify the emitter
HAZARD DISTANCE (UNCONTROLLED): the calculated lower tier hazard distance in feet
ANTENNA TYPE: As described by manufacturer or other
HAZARD DISTANCE (feet): the calculated controlled hazard distance is in feet.
PLATFORM DESCRIPTION: Deployment of the emitter (by aircraft or other if applicable).

1st Note: Hazard distances in the RF Emitter database are noted as "controlled" and "uncontrolled." These refer respectively to Upper Tier and Lower Tier MPE hazard distances.

2nd Note: When identifying unique emitters in the database; designations signifying specific military electronic and communications equipment is normally used. On the front of many pieces of military electronic equipment is a name plate displaying a group of letters and numbers which identify the gear by "code designators." When equipment is procured for the military, equipment model numbers are assigned in accordance with the **J**oint **E**lectronics **T**ype **D**esignation **S**ystem (JETDS). The first two letters are AN. This is the service indicator meaning Army-Navy but does include Air Force. AN is followed by a slant and three identifying letters. The AN system for nomenclature dates back to around 1945.

FIRST LETTER - Type of installation.

SECOND LETTER - Type of equipment.

THIRD LETTER - Purpose of equipment.

NUMERICS - Denotes the specific model of equipment.

Example: AN/UPD501 means: AN is Army-Navy, U is Utility, P is Radar and 501 - 500 is a Canadian series, so 501 is the first device in this series.

See MIL-STD-196E for the complete breakdown and reasoning of all letter and number codes.

Appendix C

Survey of Ground Based Emitters

a. These systems will generally bear "AN" nomenclatures beginning with the letter F, M, G, or T, denoting the following (with examples):

(1) Fixed (AN/FPN-49, AN/FPS-116, AN/FRT-50)

(2) Mobile (AN/MPN-14D, AN/MPS-09, AN/MRC-113)

(3) Ground (AN/GPN-22, AN/GRC-106, AN/GRN-19)

(4) Transportable (AN/TPS-73, AN/TRC-97, AN/TPB-001C)

b. Ground mounted radar systems are sometimes capable of operating in more than one mode. It is, therefore, vital that during the pre-survey, careful consideration be given to all of the possible modes to insure that measurements will be made with the system operating in the mode that will create the "worst case" (highest peak power, highest duty factor, and narrowest beam configuration).

c. A visual inspection of the site should be made to determine if the main radiated beam is normally accessible to personnel. If not, then there is no hazard, but it must be recognized that there may be future modifications of either the emitter itself or the environment that may make the beam accessible.

d. If the main beam is normally accessible to personnel, antenna rotation (if applicable) must be stopped and access to the main beam gained at a distance from the antenna determined during pre-survey. The beam size, shape, and character should be determined, and then the actual MPE level should be located. In order to assure that meter readings are accurate, care must be taken to keep the probe handle parallel to the beam axis, or perpendicular to the emitter surface as appropriate. In addition, try to avoid beam reflection from nearby objects.

e. Regardless of whether or not the main beam is normally accessible, the area surrounding the antenna itself should be carefully probed for possible hazardous levels of energy, as well as a determination made as to what might be required for personnel to access hazardous levels in the immediate vicinity of the antenna.

WARNING: When surveying aperture type systems, the area between the feed-horn and the reflector is normally very dangerous, both to personnel and to the EMF power density probes.

f. Operating personnel should be asked to accurately determine the actual power input value at the time measurements were made. Many ground systems have integral directional couplers and power meters available for this purpose.

g. An inspection should be conducted to determine if the system under evaluation has adequate interlock mechanisms, and ascertain if they can be or regularly bypassed for routine maintenance purposes.

h. A visual inspection should be made to determine if there are EMF warning signs) are in sufficient numbers, and at appropriate locations.

i. Operations and maintenance personnel should be interviewed relative to their acquaintance with the potential health hazards associated with radio frequency radiation emissions. It is often possible to gain further insight into this topic by observing the activities of these personnel as they go about their normal activities. Technical Orders for each emitter being evaluated should be reviewed for the presence and adequacy of warnings to personnel regarding these hazards. It should also be determined if there are up-to-date written operating and accident reporting standard operating procedures (SOPs) that provide acceptable personnel protection. SOPs are more important than the TO as far as review by BE is concerned.

Appendix D

Survey of Airborne Emitters

a. These systems usually bear "AN" nomenclatures beginning with the letter A, like AN/APQ-113, AN/APN-59E, AN/APG-63, AN/ASG-33, etc. During the presurvey phase of an evaluation, an assessment must be made to be certain that no emitters of interest have been overlooked because of an atypical nomenclature.

b. When airborne systems are live-fired on the ground, the main beam is almost always normally accessible to personnel, and the possible hazards must be recognized by both operating and survey personnel prior to measurements.

c. Airborne antennas, in general, and RADAR antennas especially are often at or "very near eye-level, and it must be recognized that, in the normal course of operations, the main beam is often directed downward.

d. Airborne RADAR systems are often capable of operating in many modes. It is "vital that an adequate pre-survey analysis be accomplished to insure that measurements will be made with the system operating in the mode that will create the "worst case" (highest average power output and narrowest beam widths).

e. When surveying airborne systems, it is essential that the aircraft be positioned with an ample clear area in front of the antenna to preclude unnecessary radiation of other aircraft, vehicles, buildings, etc. This distance should be determined during the pre-survey. The antenna should be stopped and positioned dead ahead in azimuth, and at zero degrees or slightly above in elevation. This last point is necessary to prevent reflections from the ground and thus create unwanted, unpredictable, and possibly dangerous "hot spots."

f. The antenna should be approached from a known safe distance (based on calculations or other source) and the main beam located. Once found, its size, shape, and other characteristics should be determined; finally the boundaries for the MPE should be defined. Care must be taken to maintain the probe along the main beam axis.

g. The area immediately surrounding the antenna (to the side and behind) should be probed for hazardous side lobes and back scatter. These are not commonly seen. As with ground aperture systems, the area between the feed-horn and the reflector is very dangerous and should be avoided by both the survey instrument and personnel.

h. It is highly desirable to evaluate a minimum of three transmitters (i.e., three different aircraft) of a given emitter. In addition, actual power input values should be obtained from operating personnel if possible. Many airborne systems have integral direction couplers for this purpose.

i. The potential for personnel EMF hazards in the avionics maintenance shops is great. Most systems are ordinarily fired into dummy loads in the shops, but some require actual radiation through an antenna. In the former case, the dummy loads should be evaluated for effectiveness, in the latter case, the evaluation should be similar to that of an aircraft mounted system and should include a careful evaluation for possible reflections and scattering within the shop area. An inspection should be conducted to make certain that the area immediately in front of any radiating antenna is off limits to personnel, vehicles, etc., to a distance appropriate for the emitter.

j. The shop area should be inspected for the presence of EMF/RF warning signs (if warranted) in sufficient numbers and at appropriate locations.

k. Both operation and maintenance personnel should be interviewed relative to their acquaintance with the potential health hazards associated with radio frequency emissions. In addition, it will be useful to observe their activities in the shop and on the flight line to gain some perception of their attitudes regarding these hazards.

l. Technical Orders for each emitter being evaluated should be reviewed for the presence and adequacy of warning to personnel regarding EMF hazards. It should also be determined if there are up-to-date written operating and accident reporting SOPs that provide acceptable personnel protection.

m. During flight line measurements, observations should be made to determine if there are adequate and effective procedures to protect personnel during routine ground firing of these systems.

Appendix E

Survey of Non-Antennae EMF Field Generators

a. The most common non-antennae EMF field generator is the diathermy machine. These units can usually be found in the physical therapy section of USAF hospitals and clinics. Medical diathermy machines in the U.S. are authorized to operate on a number of frequencies, but by far the most common are 13.56 and 27.12 MHz (short wave diathermy) and 2450 MHz (microwave diathermy). Most units within the Air Force Medical Service are short wave diathermy.

The prime concern in evaluating diathermy units is NOT with the patient undergoing therapeutic EMF treatment. Incidental exposure to medical personnel and others in the area during operation would be exposures that should be limited and require evaluation by BE. There are some potential hazards to operators of this equipment, particularly the S-band units (2450 MHz). Evaluation may be necessary to be assured that the therapists operate the equipment in a manner that will not cause them to be unnecessarily exposed, particularly to the head and shoulders. It is important to note that the proper equipment for measuring short wave diathermy units is not available at most bases. Necessary equipment can be loaned by USAFSAM upon request.

b. EMF sealers and heaters generate, by means of electronic circuitry, oscillating fields of EMF. EMF sealers generally operate within the band of frequencies from 10-70 MHz, although most of the sealers operate at nominal frequencies from 13-40 MHz. A few wood glueing machines operate at frequencies as low as 3-6 MHz, and a few EMF heaters used for plastics operate at frequencies as high as 300-400 MHz. Measurements have been made of electric and magnetic field strengths, in the immediate area of an operator as great as 2000 V/M and 10 A/m, respectively. The majority of EMF units typically leak stray energy in excess of 200 volts/meter or 0.5 amperes/meter.

Humans can absorb EMF energy at the frequencies used by most EMF sealers and heaters. In workers who are not in contact with an electrical ground, the highest absorption rates for whole-body irradiation can occur at frequencies between 60-100 MHz with a peak at approximately 80 MHz. These frequencies of high absorption rates are very close to the frequencies used by most sealers and heaters. Hence, workers near EMF sealers and heaters can absorb considerable amounts of the stray energy emitted from the EMF machines. Effects of directly touching an electrically ground plane can lower, by as much as one half, the frequency at which an irradiated body will maximally absorb energy. Contact of the worker with an electrical ground plane can shift the frequency of maximum absorption rate to well within the frequency band of most EMF sealers and heaters; this could increase the amount of energy absorbed by the worker and worsen the exposure condition. EMF shielding material incorporated into the floor, walls, and ceiling of some EMF work areas could constitute such a ground plane.

Appendix F

EMF Survey Checklist

Pre-Survey Phase

- ☐ Contact person(s) in charge; obtain and record:
  - ☐ Exact location of emitter
  - ☐ Description of emitter environment
  - ☐ Names, office symbols, and extensions of person(s) that are knowledgeable and/or responsible
  - ☐ Emitter operating parameters (transmitting)
- ☐ Coordinate arrangements for the survey:
  - ☐ Date and time when the emitter will be available
  - ☐ Personnel to operate the system
  - ☐ Mobile lifting equipment, climbing gear, etc., as required
  - ☐ Miscellaneous support equipment
- ☐ Ensure other required safety controls are in place:
  - ☐ Sector or azimuth blanking as needed to enter fields
  - ☐ Hazards related to accessing remote locations
  - ☐ Elevated work hazard controls in place
  - ☐ Lock-out/Tagout in place if needed to access around moving antenna
- ☐ Perform calculations:
  - ☐ Estimate hazard distance
  - ☐ Probe burnout levels
  - ☐ Probe corrections factor
- ☐ Check equipment:
  - ☐ Battery levels
  - ☐ Probe and meter function
  - ☐ Emitter frequency within probe frequency range
  - ☐ Calibration due date
  - ☐ Operator's Manual for meter available

Survey Phase

- ☐ Contact person(s) in charge; inbrief as necessary
  - ☐ Arrange for emitter set-up in "worst-case" mode
  - ☐ Using correct technique, locate and record (if practical):
  - ☐ MPE hazard radius and height above ground
  - ☐ Denote all areas that the MPE could be exceeded
  - ☐ Verify that the emitter is transmitting and not just receiving
  - ☐ Take measurements in W/m^2, A/m and V/m (as necessary) for the power density, magnetic and electric fields respectively moving from the far field and working towards the near field.
  - ☐ Check levels at work stations and "normally-accessible" areas

- Consider the fact that if measured emitter values are found to be well below theoretical calculated values; there may be leaks (i.e., waveguide leaks).
- Any “hot spots”
- Use the non-mandatory Table F-1 Installation Checklist as needed

- Observe and note:
  - Adequacy of warning signs and access-limiting devices (See table below for trigger levels for engineering and administrative controls)
  - Adequacy of any standard procedures used to reduce or avoid exposure to EMF
  - Degree of caution exercised by workers about handling a suspected overexposure
  - Outbrief as necessary

Post-survey Phase

- Analyze results; formulate conclusions and recommendations
- Prepare report for concerned offices, the emitter POC and to installation Safety Engineering (AF/SE)
- Enter applicable data in DOEHRS
- File data, photographs, drawings, correspondence, etc., in shop folder (electronic and paper as available)

Table F-1. Installation Program Checklist (from AFOSH 48-9 Table A4.2)

The following checklist is found on the last page of AFOSH 48-9. It is an auditing tool that can also be used to cross-verify installation compliance. For each installation emitter, the calculated SAR can be applied against the required actions. It is non-mandatory.

Area	SAR Upper Limits as W/kg			Actions Required (Shaded areas if needed)
	WBA	Local	Extremity	
Lower Tier	< 0.08	< 2	<5	None
Action Level	0.08	2	5	Notice Posting
				Documented Training
				IH Surveillance Report
Upper Tier (MPE Reference Level))	0.4	10	20	Caution Posting
				Documented Training
				IH Surveillance, Site Inspection and EMF Measurement Surveys
				Report and DOEHRS Entry
				Engineering, Physical and/or Administrative Controls
				Accident/ Incident Reports
Exposure Level (5X Upper Tier MPE)	2	50	100	Warning Posting
				Documented Training
				IH Surveillance, Site Inspection and EMF Measurement Surveys
				Report and DOEHRS Entry
				Engineering, Physical and/or Administrative Controls
				Medical surveillance
				Accident/Incident Reports w/ Medical Evaluation
Adverse Health Effects Threshold (10X Upper Tier MPE)	4			Danger Posting
				Documented Training
				IH Surveillance, Site Inspection and EMF Measurement Surveys
				Report and DOEHRS Entry
				Warning Devices or Interlocks
				Engineering, Physical and/or Administrative Controls
				Medical surveillance

The specific absorption rate (SAR) expressed in W/kg of tissue is calculated by:

$$SAR = W/m^2 \times PW \times PRF \times 0.025$$

Equation 16. Specific Absorption Rate (SAR) Calculation

where:

W/m^2= equivalent plane-wave power density (estimated by calculation or by monitoring);
PW = effective pulse width of EMF source (s)
PRF = pulse repetition frequency of EMF source (s^{-1});
WBA = Whole Body Average
Local = "Localized" and 0.025 = maximum normalized SAR (W/kg) per W/m^2 in the human body exposed to a 70-MHz EMF field.

Appendix G

Typical Beam Pattern Shape, Gain, and Widths for Common Antennas

1. Introduction

a. One challenge in maintaining an EMF emitter inventory is recognizing the EMF emitters themselves. With all of the strange looking equipment on Air Force bases, how does one tell what radiates and what doesn't? The shop personnel can be a great help, but you can also help yourself by keeping your eyes open for one of the basic elements of an EMF emitter; the antenna. Antennas come in a wide variety of shapes and sizes. Practically anything, from a small slot or stub on an aircraft fuselage, to a large array of monopoles on a hillside, can act as an antenna.

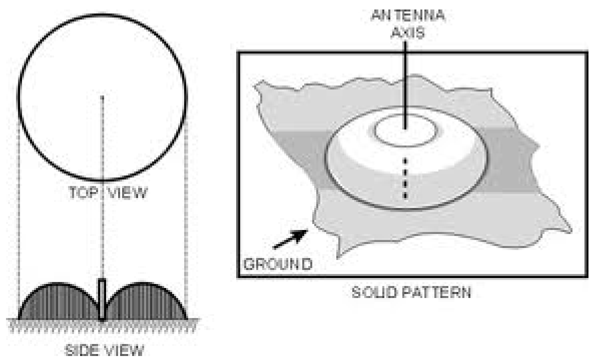
b. Another challenge that the BE shop personnel have is collecting proper emitter parameters so they can accurately evaluate an emitter. Technical Orders (TOs) are a good source of information, but TOs are often unavailable or contain information that is too generic or ambiguous to be much help. Workplace personnel are often helpful, but they may not know the specific parameters that you need, or they may give parameters that just don't make sense.

c. In this appendix we will describe a variety of antennas and give typical parameters for them. We hope that this information will save a lot of time in the day to day base level EMF work.

d. Omnidirectional Antennas:. Antennas that direct their energy in all directions are considered omnidirectional. Omnidirectional antennas are used for broadcast purposes, where a wide area of coverage must be achieved. TACAN is an example of an omnidirectional antenna.

(1) Monopoles: Monopoles, also called whips, have wide application in communications. They are used for hand-held radios, vehicle mounted radios, AM broadcast stations, and many other broadcast uses. They are usually mounted vertically to the ground plane. Their radiation pattern typically covers 360° in the horizontal plane, and is squeezed down in the vertical plane to give greater coverage range. Monopoles have gains of 1-6 dB. Figure G-1 shows diagrams of monopole antennas and Figure G-2 shows their typical radiation pattern.

Figure G-1. Monopole Antennas



Top View

Figure G-2. Radiation Pattern of Monopole Antennas

(2) Long Wire Antennas: They are a simple long wire (or beverage antenna) that behaves as an omnidirectional antenna if it stands alone away from other wires and the ground plane. There is no standard design and it is not a desirable antenna because its radiation pattern has too many large lobes and zeros. More often, long wires are combined into arrays that magnify one lobe and cancel the others out. Long wire array antennas such as V-antennas and rhombic antennas are considered directional antennas.

(3) Blades, Stubs, and Fins: (Figure G-3) Usually found on aircraft fuselage, blades, stubs, and fins and may have small radomes covering the monopoles or other omnidirectional antennas.

Figure G-3. Blade, Fin, and Stub Antennas

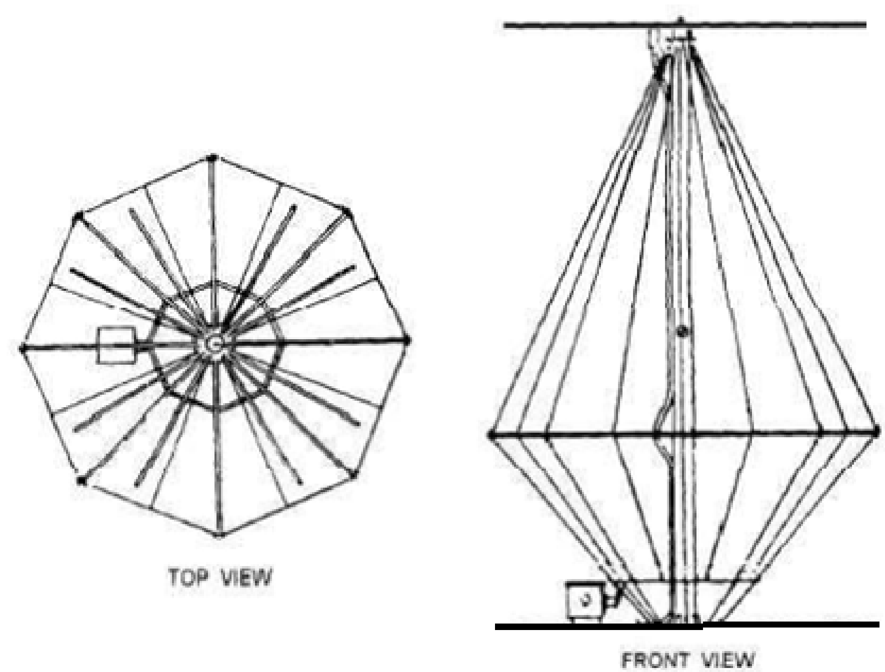


Figure G-4. Discage Antenna

Figure G-5. Discone Antenna

(4) Discage and Discone Antennas:. The discage and discone are most commonly used as low-gain wideband antennas. Each are named for the “disk” on top and the “cone” and “cage” on the bottom shapes. Discage’s lower structure operates as a cage monopole for the 4- to 12-

MHz frequency range. The upper portion of a discage operates as a discone radiator in the 10- to 30-MHz frequency range. Discage antennas (Figure G-4) are outmoded and rarely seen. Discone antennas (Figure G-5) are very common and ideal for VHF/UHF (typically 25-300 MHz) applications; having their greatest sensitivity in parallel or almost parallel to the earth's surface. They are popular as police, fire, emergency and scanner band antennas.

(5) Dipoles: Dipole antennas are extremely common in all EMF applications. They are used most often as part of other antenna structures. Yagi arrays, phased arrays, log periodic arrays, and aperture antennas are a few examples of antennas that incorporate dipoles. A single dipole has a radiation pattern shaped like a torus (a donut) with the dipole itself through the hole, and a gain of 1-4 dB. However, in combination with other dipoles, passive elements, or reflectors, the characteristics can vary greatly. Figure G-6 shows diagrams of some dipole antennas and Figure G-7 shows the typical radiation pattern.

Figure G-6. Dipole Antennas

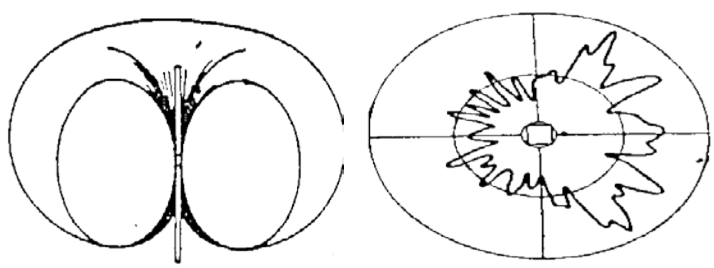


Figure G-7. Radiation Pattern of Dipole Antennas

e. Special Case Omnidirectional

(1) Helical Antennas: (Figure G-8) A helical antenna can behave as an omnidirectional antenna if the dimensions of the helix are small compared to the wavelength. This mode is not very efficient and is seldom used.

(2) Biconical Horns: A biconical horn antenna is a special case of a horn antenna that is omnidirectional. The biconical horn allows the vertical radiation pattern to be varied by changing the flare angle and side length. Depending on feed arrangement, the radiation field can

be either horizontally or vertically polarized. Their gain is highly variable, but is usually between 1-6 dB. Figure G-8 shows a diagram of a biconical horn antenna.

(3) Spiral Antennas: Spiral antennas (Figure G-8) belong to the class of frequency independent antennas which operate over a wide range of frequencies. Polarization, radiation pattern and impedance of such antennas remain unchanged over large bandwidth. Such antennas are inherently circularly polarized with low gain. Array of spiral antennas can be used to increase the gain. Spiral antennas are reduced size antennas with its windings making it an extremely small structure.

Figure G-8. Biconical Horn, ………Helical……………. and Spiral Antennas

f. Directional Antennas: Directional antennas are used for radar, point-to-point communications, and navigation purposes when the energy from an EMF emitter needs to be focused into a specific sector. This focusing usually results in higher power densities, longer range, and greater hazard distances.

g. Aperture Antennas: Aperture antennas are used to concentrate energy into a very small area. They are used for radar purposes on aircraft and are also mounted on towers or on the ground. Aperture antennas include reflector antennas and plane and conical horns.

(1) Reflector Antennas: Reflector antennas are made up of two basic parts, the feed and the reflector. The feed is usually a horn or a dipole that directs its energy into the reflector. The reflector (also called the dish or the sail) directs the energy from the feed into space. The reflector can be round/circular, elliptical, rectangular, half moon, or any other shape imaginable. Round reflectors generally result in symmetrical beam patterns called "pencil beams" with gain about 35-60 dB. Non-round reflectors usually result in nonsymmetrical beam patterns called "fan beams" with gains of 25-40 dB. For fan beams, the longest dimension of the beam width is oriented with the shortest dimension of the reflector. Figure G-9 shows diagrams of typical reflector antennas and their radiation patterns.

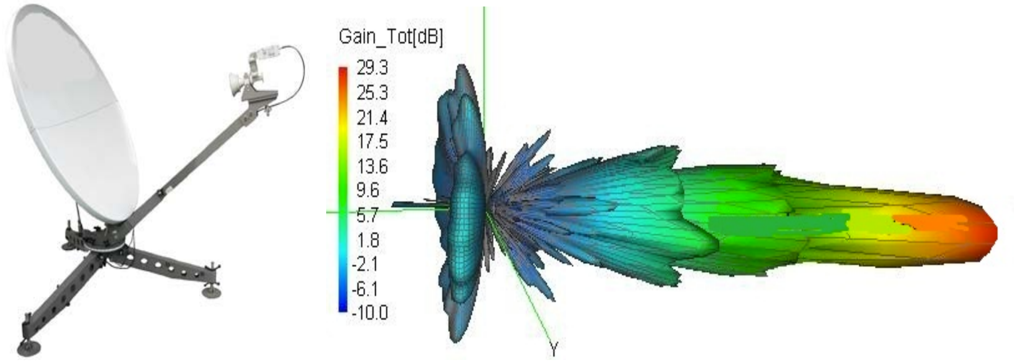


Figure G-9. Typical Reflector Antenna and Radiation Pattern

(2) Horn Antennas: Horn antennas, except for biconical horns which are omnidirectional, have patterns similar to reflector antennas. Horns can generate pencil beams and fan beams, but their gains are only 15-25 dB. Ridged or conical horns are used on aircraft, test sets, speed radar and as feed for other antennas. Figure G-10 shows diagrams and typical radiation patterns of some horn antennas.

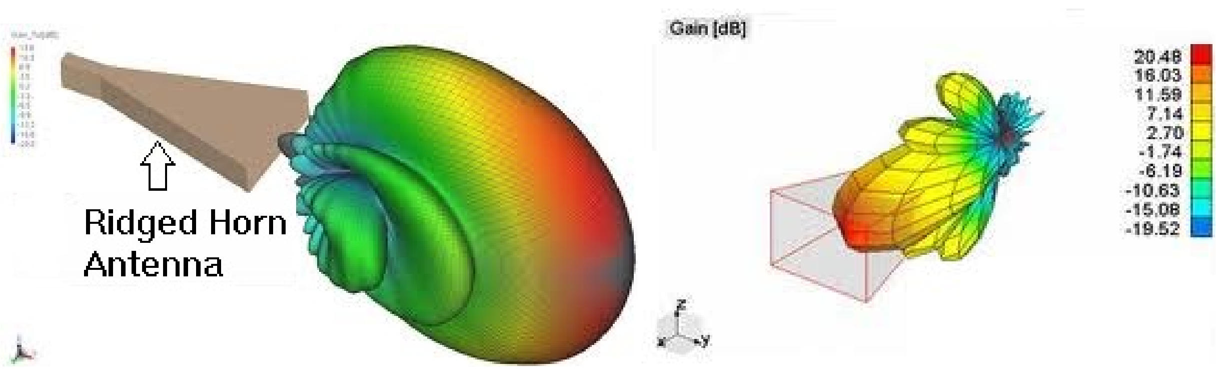


Figure G-10. Typical Horn Antennas and Radiation Patterns

h. Array Antennas: Array antennas are also used to form directional beams, but instead of mechanical reflectors, they use electronic means to direct the energy.

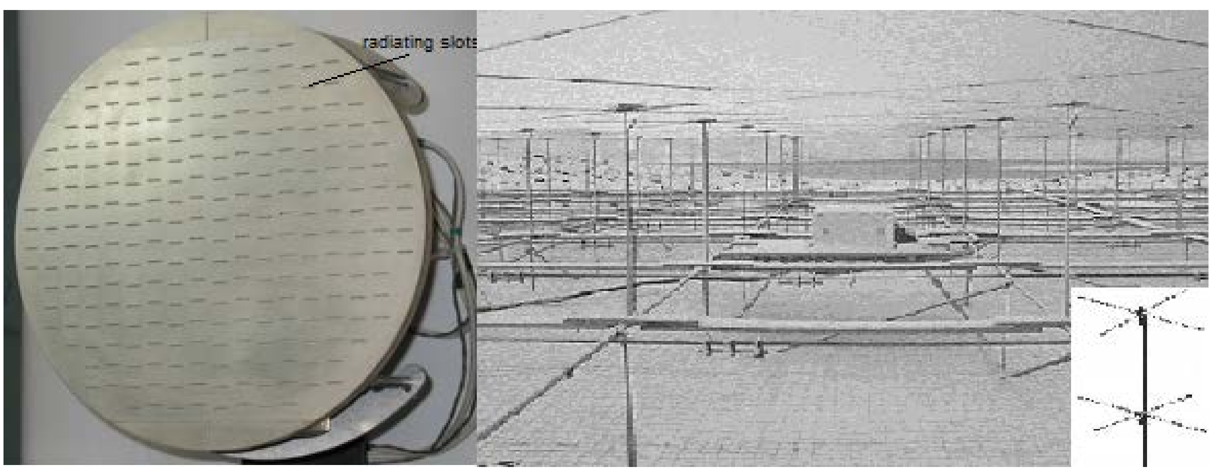
(1) Phased Arrays:. Phased array antennas are made up of a number of individual radiating elements. The elements are independently varied in phase and amplitude to produce different beam configurations. Phased array antennas are currently used for a great number of radar applications because of their excellent beam shaping and scanning capabilities and their frequency agility. The following examples illustrate the wide range of beam configurations and scanning characteristics possible with phased array radars.

- The AN/TPS-70 radar is a 3-Dimensional phased array radar operating as a single-channel, search and secondary mobile system that provides the operator with the capability to track 500 targets, displaying target range, height, azimuth, Identification Friend/Foe (IFF) information from an altitude of 0 to 100,000 feet to a maximum range of 240 nautical miles. This phased array antenna (E/F-band -2 to 4 GHz) can be used to generate several conventional beam patterns with one antenna.

- The AN/FPS-85 can detect, track and identify up to 200 satellites simultaneously. The maximum beam deflection is 60 degrees on either side of the antenna center line which provides 120 degrees azimuth of azimuth coverage. It has an average power of 40 KW and operates around 440 MHz. It is the most powerful radar in the world and is the only phased array radar capable of tracking satellites in deep space orbit.

- The AN/FPS-115 PAVE PAWS phased array radar is a large ground based search and track radar. The PAVE PAWS radar has a single beam configuration that scans electronically in a pseudorandom pattern.

Gain for phased array antennas could vary greatly, but typically it will be in the 20-60 dB range. Figure G-11 shows diagrams of a turnstile dipole array like the PAVE PAWS, and an open waveguide array like the AN/TPS-70.



Open Waveguide Array Turnstile Dipole Array

Figure G-11. Typical Phased Array Antennas

(2) Arrays of Linear Elements: Directional arrays can be made from a number of omnidirectional elements. This is done by arranging each element so that the energy is amplified in one direction and cancelled in all others. Linear arrays are usually used for point-to -point communications. Figure G-12 shows the typical radiation pattern for a linear array antenna.

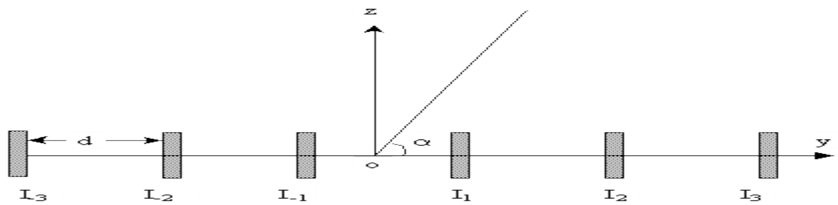


Figure G-12. Radiation Pattern for Linear Array Antennas

(3) Yagi Arrays: Yagi arrays are made up of one driven dipole and a series of passive (parasitic) elements. The passive elements serve to reflect or direct the energy from the driven element. Yagi arrays are most commonly used as television reception antennas, but they can also be used for transmissions. Typical gains for Yagi arrays are 10-15 dB. Figure G-13 shows diagrams of Yagi antennas.

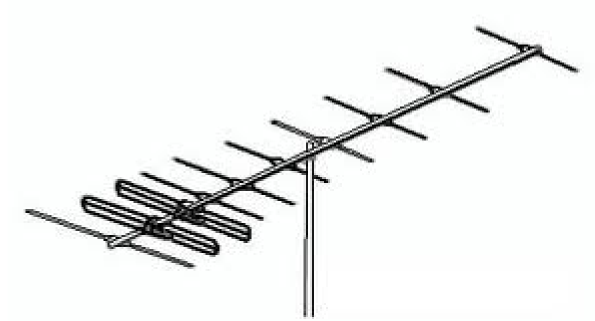


Figure G-13. Typical Yagi Antennas

i. Log Periodic Antennas: Log periodic antennas (vertical or horizontal) are made up of a series of dipoles of different lengths. Because the different size dipoles respond to different frequencies, log periodic antennas can be used for a range of frequencies. Like Yagi arrays, log periodic antennas are commonly used for television reception. Typical gains for log periodic antenna s are 10-15 dB. Figure G-14 shows diagrams of some log periodic antennas.

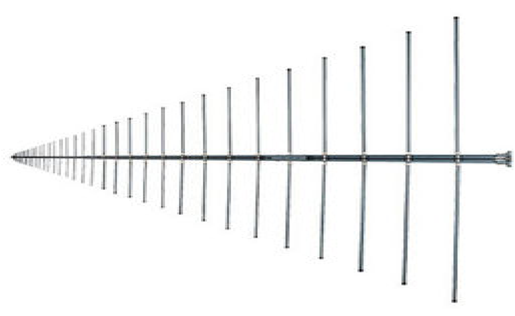


Figure G-14. Typical Log Periodic Antenna

j. Rhombic and V Antennas: Rhombic and V antennas are made of a series of long wire antennas positioned to amplify one lobe and cancel all others. These antennas (Figure# 15) can be either ground based or mounted on aircraft. They have typical gain s of 15-25 dB.

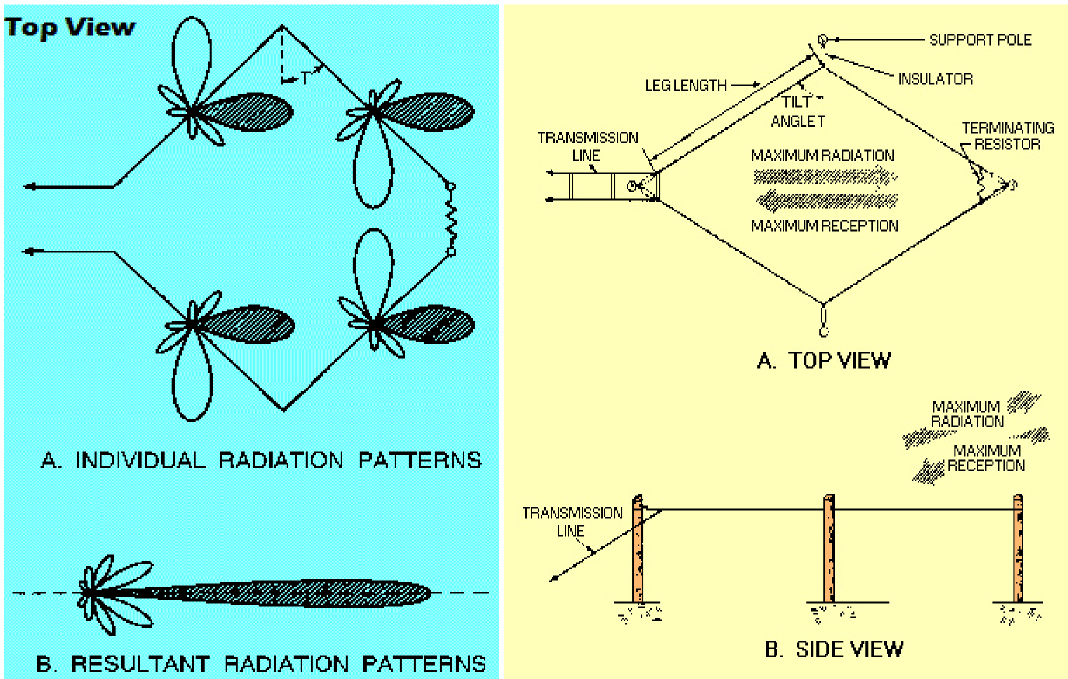


Figure G-15. Typical Rhombic and V Antennas

Appendix H

Basic Emitter Evaluations with Detailed Calculations

Example 1:

a. You investigate AN/TPQ-43 (SEEK SCORE bomb scoring radar system) with the following parameters. This is an omnidirectional radar system. Calculate the approximate MPE distance.

Frequency = 8500 - 9600 MHz
Pulse Repetition Frequency = 512 pps
Antenna Diameter = 6 feet (1.8 meters)
Antenna Gain = 42 dBi
Frequency's Upper Tier MPE = 100 W/m^2
Peak Power = 195 kilowatts
Pulse Width = 1 μs
Beam Width = 1.3°
Gain = 42 dBi
Wavelength = 0.033 meters

Figure H-1. TPQ-43

b. Our first step in solving this problem is to approximate the hazard distance with the MPE distance equation (Equation 10). All the parameters necessary for the equation are given above; however, we must first calculate the average power and convert antenna gain to absolute units. Average power can be calculated with Equations 2 and 3; gain conversion is given in Equation 7.

(1) $DF = PW \times PRF,$

$= 1\mu s \times 512$ pps,

$= 1 \times 10^{-6} s \times 512$ pps,

= 5.12 x 10-4

(2) $P_{avg} = P_{peak} \times DF,$

= 195 kW X 5.12 X 10-4

= 99.84 watts

= 100 watts

(3) Convert Gain to $Gain_{abs}$:

$$Gain_{abs} = \text{antilog [Gain (dBi)/10]} = \text{antilog [42/10]}$$

$$= 15849$$

(4) The approximate hazard distance is calculated as follows:

$$D_{MPE} = \sqrt{\frac{\boldsymbol{P_{ave}(watts)\, x\, G_{abs}}}{\boldsymbol{4\, x\, \pi\, x \left(MPE\left(\frac{W}{m^2}\right)\right)}}} = \sqrt{\frac{100W\ x\ 15849}{\boldsymbol{4\, x\, \pi\, x \left(100\left(\frac{W}{m^2}\right)\right)}}}$$

= 35.5 meters or 116 feet

(Using constant: 3.28 feet = 1 meter)

(5) Power density at a different range can be calculated using the values from above. Assume a worker stood in front of the previous emitter at a range of 20 meters. This is how their exposure could be calculated without taking measurements within the field):

$$\text{Power Density:} \quad (W/m^2) = \frac{P_{ave}\ x\ G_{abs}}{4\ x\ \pi\ x\ [D(meters)]^2}$$

$$= \frac{100\ \text{Watts}\ x\ 15849}{4\ x\ \pi\ x\ 20\ \text{meters}^2} = 315\ W/m^2$$

$(20^2 = 400)$

c. The second step in our evaluation is to determine the validity of our calculated hazard distance by determining the near- and far-field boundaries for the emitter. For an aperture emitter operating above 300 MHz, we will use Equation 11 to estimate the far-field boundary and Equation 15 for the near-field boundary.

d. From the calculations provided, it is clear that the estimated hazard distance of 116 feet is on the fringes of the near-field zone and therefore is likely to be quite conservative as compared to the actual hazard distance.

e. The following measurement values are provided to illustrate actual main beam power density values in the near-field of an emitter. Note they are quite different than calculated. The following are documented values are based on USAFSAM measurements of the AN/TPQ-43:

Table H-1. USAFSAM EMF Meter Measurements

Distance (feet)	Power Density (W/m^2)	Distance (feet)	Power Density (W/m^2)	Distance (feet)	Power Density (W/m^2)
2	110	38	50	60	43
7	100	40	45	69	50
10	65	41	50	75	60
15	55	44	45	80	40
23	55	46	40	85	40
25	80	49	40	108	30
10	75	53	45		
33	70	56	40		

f. The conclusion of the USAFSAM report recommended a hazard distance of 10 feet versus our calculated distance of 116 feet.

Example 2:

a. The AN/TPS-75 represents a typical USAF inventory ground-based tactical air defense rotating radar. It employs the Ultra-Low Sidelobe Antenna (ULSA) which decreases sidelobe emission by more than 50% and considerably reduces vulnerability to anti-radiation missiles. The radar uses Barker Phase Coded pulses to increase range accuracy and resolution. Pulse-to-pulse frequency diversity is used to decrease vulnerability to jamming (JATS).

Figure H-2. AN/TPS-75 Search Radar at Keesler AFB

Frequency = 2.9 - 3.1 GHz	Peak Power = 2.8 MW
Pulse Repetition Frequency = 275 pps	Antenna Gain = 34-38 dBi
Power Average = 5.236 kW	Beam Reflector Height= 11 feet
Absolute Antenna Gain = 6309.6	Vertical Width = 8.0°
Horizontal Beam Width = 8.2°	Reflector Width = 18 feet 4 inches
Pulse Width = 6.8 ±0.25 µs	Vertical beam width = 6.5 rpm (six and half revolutions in one minute)

1.1 degrees horizontal and 1.55 degrees to 8.1 degrees with a total of 20° (6 stacked beams)

Upper Tier MPE: 96 W/m^2 at 2900 MHz and 100 W/m^2 at 3100 MHz. Since the frequency crosses two different MPE ranges, use the more conservative of the two levels (96 W/m^2.)

$$\lambda = c / f$$
$$= (3 \text{ x } 10^8 \text{ m/s}) / 2.9 \text{ x } 10^9 \text{Hz})$$
$$= 0.103 \text{ meters,}$$

b. Hazard distance calculation- taking into account this is a rotating antenna and using the appropriate formula:

$$D_{MPE} = \sqrt{\frac{P_{avg} \times G_{abs} \times RRF}{4 \ \pi \ \ MPE}}$$

Duration of one exposure in front of antenna: 1.1°/360° rotation = RRF = 0.003

$$D_{MPE} = \sqrt{5236 \text{ x } 6309.6 \text{ x } 0.003 / 4 \text{ x } \pi \text{ x } 96 \text{ W/m}}^2$$

$$= 9.06 \text{ meters or 30 feet}$$

If this radar system were stationary, the D_{MPE} would be roughly 543 feet. This helps illustrate the reduction in energy when an antenna is rotational (18 times less in this case.)

c. Where the frequency, f, is the median value between 2.9 - 3.1 GHz.

$$\text{Near-Field} < L^2 /[4 \text{ x } \lambda],$$

$$< 5.612 \text{ m}^2 / [4 \text{ x } 0.1 \text{ m}], < 31.42 \text{ meters}$$

where, our value for L in the near-field equation is the longest dimension of the antenna, the reflector width of 18 feet four inches; note the conversion from feet/inches to meters:

$$18.33 \ feet \ x \ \frac{1 \ meter}{3.28 \ feet} = 5.61 \ meters$$

d. From the calculations above, it is apparent that the individual was located well within the near-field of the emitter and, therefore, near-field estimation is most appropriate.

e. Let's temporarily forget that this radar system is rotational and calculate the power density:

To estimate the main-beam power density, we will use Equation 13. Since antenna area is not given in our list of parameters, we must first calculate the area of the reflector. The reflector is rectangular in shape. Antenna area is calculated as follows:

Area = reflector length x reflector width

= 18 feet 4 inches x 11 feet = 201.6 feet^2,

$$= 201.6\, feet^2\, x \quad \frac{1\, meter}{3.28\, feet}\; x\; \frac{1\, meter}{3.28\, feet} = 18.7\, m^2$$

Calculated Power Density (for the far field)

= (4 x P_{avg}) / Antenna Area

= (4 x 5236W)/18.7 m^2

= 1120 W/m^2
(this is a stationary value (not rotational)

Now multiply the calculated power density by the RRF value (0.003) to get the true rotational antenna far-field power density:

1120 W/m^2 x 0.003 = 3.36 W/m^2

This data corresponds relatively well with a consultative letter by USAFSAM Letter AL/OE-CL-1997-0126 “Radio-Frequency Radiation Hazard Survey of Selected Emitters at Luke AFB AZ; where the report documents a “field measured” maximum power density of 2.6 mW/cm^2 (26 W/m^2) at 20 feet from the AN/TPS-75 antenna.

f. Using the 20 feet as the distance to compare power density with the D_{MPE} (65.6 meters):

Power Density(PD): $(W/m^2) = \frac{P_{ave}\, x\, G_{abs}}{4\, x\, \pi\, x\, [D(meters)]^2}$

$$611\ W/m^2 = \frac{5236\ Watts\ x\ 6309.6}{4\ x\ \pi\ x\ 65.6\ meters^2}$$

(65.6^2 = 4303.4)

The effective power density as seen from a stationary point for a scanning antenna in motion can be estimated from the power density measured with the antenna stationary using the expression:

$$(PD)_{rotational} = PD_{stationary}\ x\ RRF$$

$$1.83\ W/m^2 = 611\ W/m2\ \ x\ \ 0.003$$

g. To estimate the exposure to the individual we will perform a simple time average of the exposure over a 6-minute period as shown below:

$$\text{Power Density Average} = \frac{(180\ W/m^2 \times 45\ s) + (0\ W/m^2 \times 315s),}{360\ \text{seconds}}$$

$$= 225\ W/m^2$$

This individual was therefore overexposed since this well over 96 W/cm^2.

h. A key note to remember on time weight averages: exposure levels can never exceed the energy amounts allowed within the MPE timeframe (i.e., 6 minutes in the above calculation). One cannot simply time-weight higher exposures over a greater timeline.

i. MPE Averaging Periods.

(1) MPEs in AFOSH Table A3.1 refer to values averaged over any 6-minute period for frequencies less than 15 GHz, and over shorter periods for higher frequencies (10 seconds at 300 GHz). The MPEs in AFOSH Table A3.2 refer to values generally averaged over any 6-minute or 30-minute period for frequencies less than 3 GHz. For certain frequency intervals, the averaging period will vary as a function of frequency as shown in AFOSH Table A3.1 and Table A3.2 in Section (5.c) of this Guide.

(2) For exposure duration less than the averaging period, the maximum permissible exposure level, is MPE [T_{avg}/T_{exp}], where T_{exp} is the exposure duration in that interval expressed in the same time units as T_{avg}.

(3) For exposure durations less than the averaging time, MPEs can be increased (see examples 1 & 2 below.

Example 1: A person working in front of an emitter is exposed to a field with a frequency of 200 MHz and a power density of 20 W/m^2 for 2 minutes. (MPE is 10 W/m^2 with a 6 minute Averaging Time)

$$Adjusted\ MPE = 30W/m\hat{}2\ =\ 10W/m\hat{}2\ \ x\ \ (6\ minutes)/(2\ minutes)$$

- Since 20 W/m^2 is less than the adjusted MPE of 30 W/m^2 the person is NOT exposed above the MPE.

Example 2: A person working in front of an emitter is exposed to a field with a frequency of 200 MHz and a power density of 20 W/m^2 for 4 minutes. (MPE is 10 W/m^2 with a 6 minute Averaging Time)

$$Adjusted\ MPE = 15W/m\hat{}2\ =\ 10W/m\hat{}2\ \ x\ \ (6\ minutes)/(4\ minutes)$$

- Since 20 W/m^2 is greater than the adjusted MPE of 15 W/m^2 the person has been exposed above the MPE.

(4) For exposure durations greater than the averaging time, MPEs cannot be increased (see examples 3 & 4 below).

Example 3: A person working in front of an emitter is exposed to a field with a frequency of 200 MHz and a power density of 5 W/m^2 for 30 minutes. (MPE is 10 W/m^2 with a 6 minute Averaging Time)

$$Non - adjustable\ MPE = 10W/m\hat{}2\ =\ 10W/m\hat{}2\ \ x\ \ (6\,minutes)/(30\,minutes)$$

- Since exposure duration of 30 mins is greater than the averaging time of 6 mins, MPEs cannot be changed.

- Fortunately in this case, the exposure is 5 W/m^2 which is less than the MPE of 10 W/m^2 and the person is not exposed above the MPE.

Example 4: A person working in front of an emitter is exposed to a field with a frequency of 200 MHz and a power density of 20 W/m^2 for 30 minutes. (MPE is 10 W/m^2 with a 6 minute Averaging Time)

$$Non - adjustable\ MPE = 10W/m\hat{}2\ = 10W/m\hat{}2\ \ x\ \ (6\,minutes)/(30\,minutes)$$

- Since exposure duration of 30 minutes is greater than the averaging time of 6 minutes, MPEs cannot be changed.

- Therefore the exposure is 20 W/m^2 which is greater than the MPE of 10 W/m^2 and unfortunately this person has been exposed above the MPE.

- If the exposure had been 50 W/m2, the person would have been 5 times over the exposure limit and medical surveillance would be been triggered. See Section (9.b) for steps involving medical surveillance.

j. Rotational Reduction Factor (RRF).

Rotating antennas result in a reduced hazard. This reduced hazard is calculated using the following equation. It was used previously on the last page in the example.

$$D_{MPE} = \sqrt{\frac{P_{avg} \times G_{abs} \times RRF}{4\ \pi\ \ MPE}}$$

Equation 17. Rotating Antenna MPE Distance Calculation (Far-Field)

RRF= beam width/sector scan (rotating systems only)

- MPE is in W/m^2
- P_{avg} is typically P_{peak} converted to Pavg by Equation# 2
- Gain is dBi converted to $Gain_{abs}$ by Equation # 6
- A rotating or scanning beam likewise reduces the hazard, so although an on-axis hazard might exist, there may be none with a moving beam. The power density may be approximated with: $PD_{scan} = PD_{fixed}$ (Horizontal Beam Width / scan angle) (i.e., an antenna that rotates completely around has a scan angle of 360°.) Horizontal beam widths are typically noted with operations manuals. Do not apply the vertical beam width.

k. Multiple Emitters.

A lot of times you are in multi-emitters environments. Instead of having a probe that can read out in mW per cm^2, say for example you had a case where you had 50mW per cm^2, and you had all three of these together. If it all came from this source number one, would you be over the limit? No, because 50/100 is less than one. But what if it was 50 in the second one? You would be 50 times over the limit. A regular Narda probe has no ability to discriminate which emitter is creating fields; 50 mW per cm^2 would read 50 regardless. This is when you would want to use a Shape Probe. This reads out in percent of standard. So, in the above case, if it was all in the first emitter, what would the probe read? 50 percent. But, it would beep overload if it was the last one. These are expensive probes and there are not a lot of them out in the field.

$$\sum_{i=1}^{n} \frac{S_i^2 DF}{PEL_i^2} \leq 1$$

This is an imposing looking formula. In actuality, we'll use this formula below which is an extrapolated version of the above:

$$\text{Combined MPE} = \frac{\text{exposure level}_1}{\text{MPE}_1} + \frac{\text{exposure level}_2}{\text{MPE}_2} + \ldots \leq 1$$

Equation 18. Multiple Emitter (Theoretical and Actual) Calculation

Follow the following steps when multiple emitters are involved.

(1) Is any individual MPE exceeded?
(2) Is the combined MPE exceeded?
(3) Use the Unity Calculation:
(4) Average each exposure over 6 minutes (or appropriate averaging time)
(5) Find the MPE for each frequency
(6) See if combined MPE is exceeded

Now let’s look at some calculations of combined MPEs for areas with multiple emitters in mW/cm^2.

Example 1: Is the combined MPE exceeded if a worker is exposed simultaneously to 0.4 mW/cm2 at a freq. of 0.3 GHz (Emitter A) and 5 mW/cm2 at a frequency of 1.5 GHz (Emitter B) for 3 minutes?

Emitter "A" - 0.3 GHz = 300 MHz MPE = 1.0 mW/cm^2
Emitter "B" - 1.5 GHz = 1500 MHz MPE = 5.0 mW/cm^2

Without calculating the time weighted averages, we see the exposures are less than the MPEs.

Emitter "A- MPE" 1 mW/cm2 > 0.4 mW/cm^2
Emitter "B- MPE" 5 mW/cm2 > 5mW/cm^2

Now calculate the time-weighted averages for each:

$$\text{Emitter A}: 0.4\frac{mW}{cm^2}\times\frac{3\min}{6\min} = 0.2\frac{mW}{cm^2}$$

$$\text{Emitter B}: 5\frac{mW}{cm^2}\times\frac{3\min}{6\min} = 2.5\frac{mW}{cm^2}$$

NOTE: Be sure to check for overexposures at this point!

Individually, each emitter is less than their applicable MPEs.
Emitter "A" 0.2 mW/cm^2 < 1 mW/cm^2 (MPE)
Emitter "B" 2.5 mW/cm^2 < 5 mW/cm^2 (MPE)

Now, divide each averaged exposure by its MPE and sum the quotients

$$\frac{0.2\,\text{mW/cm}^2}{1.0\,\text{mW/cm}^2}+\frac{2.5\,\text{mW/cm}^2}{5.0\,\text{mW/cm}^2}=0.70$$ **Not Overexposed!**

Example 2:

Emitter A; Time Weight Average
1.5 * 5/6 = 1.25 < MPE of 1.5
Emitter B: Time Weighted Average
110 * 5/6 = 91.7 < MPE of 100

	Exposure Time	Frequency	Exposure Level
Emitter A	5 min	450 MHz	1.5 mW/cm^2
Emitter B	5 min	3000 MHz	110 mW/cm^2

Overexposed!

Example 3

Emitter A: Time Weighted Average
2 * 2/6 = .67 < MPE of 2.12
Emitter B: Time weighted Average
5 * 5/6 = 4.17 < MPE of 5.67

	Exposure Time	Frequency	Exposure Level
Emitter A	2 min	0.635 GHz	2 mW/cm^2
Emitter B	5 min	1700 MHz	5 mW/cm^2

$$\frac{0.67\,\mathrm{mW/cm^2}}{2.12\,\mathrm{mW/cm^2}} + \frac{4.17\,\mathrm{mW/cm^2}}{5.67\,\mathrm{mW/cm^2}} = 1.27$$ **Overexposed!**

Example 4

Emitter A: Time Weighted Average
2 * 2/6 = .67 < MPE of 2.12
Emitter B: Time Weighted Average
3 * 5/6 = 2.5 < MPE of 5.67

	Exposure Time	Frequency	Exposure Level
Emitter A	2 min	0.635 GHz	2 mW/cm^2
Emitter B	5 min	1700 MHz	3 mW/cm^2

$$\frac{0.67\,\mathrm{mW/cm^2}}{2.12\,\mathrm{mW/cm^2}} + \frac{2.5\,\mathrm{mW/cm^2}}{5.67\,\mathrm{mW/cm^2}} = 0.76$$

Not Overexposed!

l. Exposure Density.

When personnel are exposed above the MPE it is not advisable for a BEE to stand within this field to verify a high exposure level. This exposure level can be calculated when the following information is known.

- Exposure value (I_1) at another known safe distance (D_1) from the emitter
- Distance of the exposed individual from the emitter (D_2)

Example Calculated Exposure Level using the Inverse Square Law:
If the power density three feet from an antenna is 1000 W/m^2, what is the power density six feet away?

$$I_2 = I_1 \text{ X } \frac{D_1^2}{D_2^2}$$

Equation 19. Inverse Square Law Calculation

$$I_2 = 1000 \frac{\mathrm{W}}{\mathrm{m}^2} \text{x} \frac{3\, ft_1^2}{6\, ft_2^2}$$
$$I_2 = 250 \text{ W/m\^{}2}$$

This is quite valuable, as normally, leakage energy drops off as the inverse square of the distance. Therefore, one should begin by approaching a generator, antenna, or any unintended radiating/leaking structures (or broken waveguides) from a “safe” distance. The survey instrument should be set to a “high” range to alert the surveyor to the possibility of being exposed to levels exceeding the applicable MPE.
The inverse square law is also ideal for calculating exposure for distances beyond the calculated hazard distances.

Warning: The inverse-square relationship may not apply if you are close to an electrically large aperture.

m. Evaluation of Safe Occupancy Area in Front of an Angled Antenna

The distance (S) from a vertical axis passing through a dish center to a safe off axis location in front of an antenna can be determined based on the dish diameter rule per the FCC- OET Bulletin No. 65, (Exbihit C,) Edition 97-01. Assuming a flat terrain in front of the antenna, the relationship is:

$$S = (D/ \sin \alpha) + (2h - D - 2)/(2 \tan \alpha) \quad (7)$$

Equation 20. Angled Parabolic Dish Safe-Distance Calculation

Where: α = minimum elevation angle of antenna
D = dish diameter in meters
h = maximum height of object to be cleared, meters

For distances equal or greater than determined by equation (7), the radiation hazard will be below safe levels for all but the most powerful stations (> 4 kilowatts RF at the feed).
Example:

For D = 1.2 meters
h = 2.0 meters

Then:

α	S
5	18.3 meters
10	9.2 meters
15	6.1 meters
20	4.6 meters
25	3.7 meters

Appendix I

Acronyms List and Terms List

AF .... Air Force

AFI .... Air Force Instruction

AFMSA... Air Force Medical Support Agency

ASHRAE.................... American Society of Heating, Refrigerating & Air Conditioning Engineers

ASTM .... American Society for Testing and Materials

BE .... Bioenvironmental Engineering

BEE .... Bioenvironmental Engineer

BEF .... Bioenvironmental Engineering Flight

CDC .... Centers for Disease Control and Prevention

CE .... Civil Engineer

DoD .... Department of Defense

DOEHRS............................... Defense Occupational Environmental and Health Readiness System

FCC .... …………………. Federal Communications Commission

HQ .... Headquarters

MAJCOM(s) .... Major Command(s)

O&M .... operation and maintenance

OSHA.. Occupational Safety and Health Administration

PH ....Public Health

USAF ....United States Air Force

USAFSAM... United States Air Force School of Aerospace Medicine

WHO..World Health Organization

Terms List

Action level: The values of the electric and magnetic field strength, the incident power density, contact and induced current, and contact voltages above which steps shall be initiated to protect against exposures that exceed the lower tier, specifically, implementation of an EMF safety program.

Action Level Environment: Locations where EMF exposures do not exceed the MPEs in table AFOSH 48-9 A3.1 but do exceed those AFOSH 48-9 table A3.2. (i.e., where the exposure range between the Upper and Lower Tier environments resides).

Antenna: A device designed for radiating (or receiving) electromagnetic energy.

Antenna Gain: A measure of the antenna's ability to concentrate energy in a giver direction. It is usually expressed in decibels and referenced to a perfectly isotropic antenna.

Amplitude Modulation (AM): A modulation scheme in which the amplitude of the carrier is varied according to the message signal.

Athermal Effects: Biological effects not caused by heating of the tissues.

Average Power (Pavg): The time-averaged rate of energy transfer:

$$P_{avg} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} P(t)\,dt$$

Bandwidth: The width (in MHz) of the range of frequencies over which an emitter can operate.

Beam Width: The angular width of the beam defined at the half-power points.

Carrier Signal: The radio frequency signal that is modulated by the message signal.

Continuous Wave (CW): A waveform with a continuous carrier signal.

Decibel (dB): The logarithmic unit used to indicate relative intensities of power or voltage, equal to 10 times for power, and 20 times for voltage, the common logarithm of the ratio.

dBm: A logarithmic unit for comparison of power to 1 milliwatt.

dBi: A logarithmic unit for comparison of transmitted power density to that from a perfectly isotropic emitter.

Dummy Load: A dissipative device used at the end of a transmission line or waveguide to convert EMF energy into heat, so that essentially no energy is radiated outward or reflected back to the source.

Duty Factor (DF) (also called Duty Cycle or Duty Ratio): The ratio of the pulse duration to the pulse period of a periodic pulse train. This is a unit less number, expressed as a decimal, fraction, or percent, which indicates the portion of time a transmitter is actually emitting EMF energy. It is the product of pulse width (sec) and pulse repetition frequency (PRF).

Electro- Explosive Device (EED): A pyrotechnic or explosive device designed to detonate when an electric current passes through it, commonly called a squib.

Electromagnetic Interference: Interference to the operation of electrical or electronic equipment from radiated electromagnetic fields.

Electromagnetic (EM) Spectrum: The total range of wavelengths (or frequencies) of electromagnetic waves including radio frequency radiation, light, and x-radiation.

EMF "Hot Spot": A highly localized area of relatively intense EMF Field that manifests itself as:

• Intense electric or magnetic fields immediately adjacent to conductive objects immersed in lower intensity ambient fields.

• Localized areas where there exist a concentration of EMF fields caused by reflections or narrow beams produced by high-gain radiating antennas or other highly directional sources.

• For both descriptions, the fields are characterized by very rapid changes in field strength. EMF hot spots are normally associated with very non uniform exposure of the body (partial-body exposure). The term EMF hot spots should not be confused with an actual thermal hot spot in an absorbing body.

Electromagnetic Wave: A system consisting of mutually supporting, time-varying electric and magnetic fields those are perpendicular to each other and to the direction of travel. By definition, electromagnetic waves travel at the speed of light.

Emitter: Any device which is designed to generate EMF energy and couples this energy into the surrounding space. Usually includes a transmitter, a waveguide or transmission line, and an antenna or dummy load.

Equivalent Plane Wave Power Density: The normalized value of the square of the electric or the magnetic field strength at a point in the near-field of a radiating source. The value is expressed in W/m^2, (or mW/cm^2) and is computed as follows:
Power Density(S) = $E^2/377 = 377 \cdot H^2$

Exposure, Partial Body: Partial-body exposure results when EMF Fields are substantially non-uniform over the body. Fields that are non-uniform over volumes comparable to the human body occur due to highly directional sources, re-radiating sources, standing waves or when in the antenna's near-field region. For most antennas the Far-field starts at twice the diameter of the antenna divided by the wavelength.

Fan Beam: A radiation pattern similar to a pencil beam but with an elliptical cross section.

Far -Field (Fraunhofer Region): The radiation field at a distance from the antenna where the electric and magnetic fields approximate a plane wave and the power density decreases with the square of the distance.

Frequency Modulation (FH): A modulation scheme in which the frequency of the carrier is varied according to the message signal.

Hertz: A measure of frequency equivalent to cycles per second.

Indirect Biological Hazard: Hazard due to interference with electronic medical devices (i.e., cardiac pacemakers).

Isotropic Emitter: A purely theoretical emitter that distributes power equally in all directions.

Lower tier: A set of limits that provide an additional margin of safety, i.e., a margin of safety greater than that for the upper tier. *See:* action level.

> NOTE: Exposures exceeding the lower tier, are the action level above which an EMF safety program shall be implemented, recognizes public concerns, uncertainties in exposure assessment, and supports the process of harmonization with other standards.

Lower Tier Environments: Locations where EMF exposures do not exceed the MPEs in AFOSH 48-9 Table A3.2. Such locations generally represent living quarters, workplaces, or public access areas where personnel would not expect to encounter higher levels of EMF energy.
Measurement Survey: A measurement of EMF emissions using field instrumentation, to determine necessary controls or exposure levels.

Maximum Permissible Exposure (MPE): The level of EMF energy to which an individual may be exposed, that will not cause detectable bodily injury in light of present medical knowledge.

Message Signal: A signal that carries a message.

Modulation: The process where certain characteristics of the carrier signal are varied in accordance with the information in the message signal.

Near-Field (Fresnel Region): The radiation field relatively near an antenna where the electric and magnetic fields do not approximate a plane wave and the power density does not decrease with the square of distance.

Omnidirectional: A radiation pattern that distributes energy evenly in all directions in a particular plane.

Peak Envelope Power: The maximum power in a modulated signal.

Peak Power: The maximum instantaneous power output of a system.

Pencil Beam: A radiation pattern that concentrates energy in a small angular sector.

Phased Array: An arrangement of antennas in which the relative phases of the respective signals from each is varied in such a way that that beam can scan very rapidly, efficiently and suppress undesired directions; normally controlled by a computer.

Plane Wave: Propagating electromagnetic waves that are equal in magnetic and electric energy. In the far field, all waves propagate as plane waves.

Power Density: The amount of power per unit area in an EMF field, expressed in watts per square meter (W/m^2).

Pinnae: Outer ear or ear lobe.

Prefixes: When added to a unit of measure, the numerical value is multiplied by:

Tera (T)	10^{12}
Giga (G)	10^{9}
Mega (M)	10^{6}
Kilo (K)	10^{3}
Centi (c)	10^{-2}
Milli (m)	10^{-3}
Micro (μ)	10^{-6}
Nano (n) =	10^{-9}

Pulsed Waveform: A waveform that has individual pulses separated by non-transmission times.

Pulse Modulation (PM): A modulation scheme in which the carrier is a series of pulsed that are modulated by varying their amplitude, width, or phase.

Pulse Repetition Frequency (PRF): The number of pulses per second (PPS) of a pulsed transmission.

Pulse Width (PW): The duration (time) of a single pulse of a pulsed transmission.

Radio Frequency Radiation Hazard Meter (Monitor): An instrument that is capable of measuring spatially localized electric and/or magnetic field strengths under near and far-field conditions. The instrument consists of a sensor with an antenna suitable for the wavelength under study, plus a means for transmitting information from the sensor to a suitable field strength indicator.

Radar (RAdio Detection And Ranging): A system that radiates electromagnetic waves into space and uses the reflected waves to detect objects.

Site Inspection Survey: A visual inspection of an emitter site to determine if further controls or investigation are needed.

Thermal Effects: Biological effects caused directly by heating of the tissues.

Transition Region: The region between the far-field and the near-field regions where the field has some characteristics of both.

Transmission Line: The part of an emitter that carries the signal from the transmitter to the antenna.

Transmitter: Part of an emitter that generates and amplifies an EMF signal.

Upper Tier: A set of EMF exposure limits that are scientifically based and that provide a margin of safety for all, including those in an Upper Tier environment.

Upper Tier Environment: Locations where EMF exposures may exceed the levels in AFOSH 48-9 table A3.1, but do not exceed the levels in AFOSH 48-9 table A3.2. Generally, Upper Tier environments represent areas that may be occupied by personnel who accept potential exposure as a concomitant of employment or duties, by individuals who knowingly enter areas where such levels are to be expected, and by personnel passing through such areas. Existing physical arrangements or areas, such as fences, perimeters, or weather decks of a ship may be used in establishing Upper Tier environments.

Watt (W): Is a unit of power; equal to joules per second (J/s).

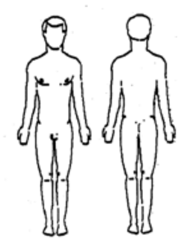
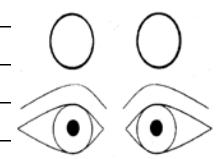
Appendix J

EMF Accident/Incident and Injury Forms

EMF ACCIDENT/INCIDENT REPORTING FORM		
Fill out all fields as applicable		
1. CONTACT INFORMATION	RADIATION SAFETY OFFICER OR OTHER	MEDICAL PROVIDER
NAME/RANK		
ORG/INSTALLATION		
ADDRESS		
TELEPHONE		
EMAIL		
2. PATIENT INFORMATION		
NAME:	FLIGHT/DUTY STATUS:	
ORG/INSTALLATION:	PHONE NUMBER:	
ADDRESS:	EMAIL:	
SERVICE COMPONENT: Army____ Air Force_____ Navy_____ Marine Corps_____		
3. EMF ACCIDENT / INCIDENT INFORMATION		
LOCATION OF ACCIDENT/INCIDENT:	DATE/TIME:	
BRIEF DESCRIPTION OF ACCIDENT/INCIDENT		
NAME/DESCRIPTION OF EMF EMITTER:		
EXPOSURE DISTANCE (meters):	EXPOSURE DURATION (seconds):	
WERE EFFECTS FELT: □ YES □ NO	Description of Effects:	
4. EMITTER OPERATING PARAMETERS		
EMITTER FREQUENCY:	PULSED/CONTINUOUS:	
PULSE REPETITION FREQUENCY:	PULSE DURATION:	
OUTPUT POWER:	ANTENNA GAIN (dB):	
ANTENNA ROTATION/SCAN RATE:	OTHER:	
5. MEDICAL FINDINGS FOR SUSPECTED EMF INJURY		
Please attach medical form (STANAG 2345 form) if personnel was referred to a medical provider		
USAFSAM/OEHT: ESOH SERVICE CENTER: esoh.service.center@wpafb.af.mil, 1-800-473-3549 DSN: 798-3764 Authority for the EMF injury hotline is derived from DoDI 6055.11		
INSTRUCTIONS: Army: DA PAM 385-24, 38 AFOSH 48-9		

<table>
<tr><td colspan="4">Name
Date of birth

Address of reporting office:</td><td colspan="3">Item/RPT N).</td></tr>
<tr><td colspan="3">Address of reporting office :</td><td colspan="4">Date/ Ref. N°. of incident :</td></tr>
<tr><td colspan="7">Type of vessel / establishment :</td></tr>
<tr><td>Location</td><td>shore based</td><td>harbor facility</td><td>vessel at harbor</td><td>vessel at sea</td><td>other (specify)</td><td></td></tr>
<tr><td colspan="7">Individual (s) concerned :</td></tr>
<tr><td colspan="7">Equipment concerned / involved in incident :</td></tr>
<tr><td colspan="7">Description of incident, including Likely cause :</td></tr>
<tr><td>Is the cause Confirmed ?</td><td></td><td>Severity of incident</td><td>A
Critical</td><td>B
Major</td><td>C
Minor</td><td></td></tr>
<tr><td colspan="3">Transmission frequency/band</td><td></td><td colspan="2">Transmitter power</td><td></td></tr>
<tr><td colspan="3">Tx mode (CW, long/short pulse)</td><td colspan="4"></td></tr>
<tr><td colspan="3">Antenna type & mode</td><td colspan="4"></td></tr>
<tr><td colspan="7">Spatial relationship of victim person or equipment to antenna :
(Consider partial body exposure)</td></tr>
<tr><td colspan="7">Length of time at this position :</td></tr>
<tr><td colspan="7">Medical actions taken :</td></tr>
<tr><td colspan="7">Actions taken to prevent repetition of incident :</td></tr>
<tr><td colspan="7">Comments :</td></tr>
</table>

General feelings: warmth/burn: weakness: spark discharge/shock: headache: fasciculation/tremor: mechanic wounds: others:
loss of balance: record of whole body temperature:
Sensorial signs: Visual: **Psychological symptoms**:
Auditory:
Date of apparition and development of symptoms:
Areas exposed: 
Physical examination*:*
blood pressure: cardiac frequency: cardiac rhythm:
neurologic examination:
dermatologic (burn, erythema, others):
Ophthalmologic examination
conjunctivas/corneas lesions/burn:  Lenses
- visual acuity without correction: Right /10 Left /10
- visual acuity with correction: Right /10 Left /10 Right Left
- visual acuity before present overexposure
- lenses and retina (fundi after dilatation):
Urine analysis
Blood count (WBC, Hb) at day 0 and day +8:
D0 *D8*
In the case of specific signs
Electro Encephalographic recording:
Electrocardiographic recording:

Appendix K

Acknowledgment Section (w/ list of contributors)

a. The original Electromagnetic Frequency Bioenvironmental Engineering Guide served to train and guide Air Force personnel for two decades. We must first thank Dr. Rademacher and Dr. Montgomery for their original work that helped so many bioenvironmental personnel including myself. We can only hope this revision lasts the test of time as well as their version. In acknowledgement of the Guide's successes, we kept their original framework.

b. While many principles stay the same in the scientific understanding of the electromagnetic spectrum, many aspects have changed in the overall health considerations and the techniques for personnel protection. Commercial use items in EMF have exploded in use. Cell phones and Wi-Fi for personal communication devices dominate today's scientific discussions on EMF.

c. The Electromagnetic Frequency Bioenvironmental Engineering Guide was revised by drawing information from a large number of published sources. Many are available online. Information to revise this guide was taken from the following abbreviated list of contributors (they are listed in no particular order):

1. American National Standards Institute/Institute of Electrical and Electronics Engineers, (ANSI/IEEE) C95.1 through C95.7., most current versions
2. Air Force Occupational Safety Health Standard (AFOSH) 48-9, 14 DEC 2011
3. SUBJECT: Protecting Personnel from Electromagnetic Fields, Department of Defense INSTRUCTION# DOD 6055.11, August 19, 2009
4. NCRP 86, *Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields*, 1986
5. American Conference of Governmental Industrial Hygienists (ACGIH) Radio-frequency and Microwave Radiation: TLV® Physical Agents 7th Edition, 2010
6. FCC- OET Bulletin No. 65, Evaluating Compliance with FCC Guidelines for Human Exposure to Radio Frequency Electromagnetic Fields (and Exbihit C,), Edition 97-01
7. Course ES310,*Introduction to Naval Weapons Engineering*, http://www.fas.org/man/dod-101/navy/docs/es310/syllabus.htm
8. Conference on "*Occupational Exposure to Electromagnetic Fields: paving the way for a future EU initiative*" IEEE EMF Exposure Standards C-K. Chou, Ph.D. Umeå, Sweden October 6, 2009
9. Narda Safety Test Solutions, EMF Training Materials and Product Literature
10. *Historical Review of RF Exposure Standards and the International Committee on Electromagnetic Safety* (ICES), John M. Osepchuk and Ronald C. Petersen, Bioelectromagnetics Supplement 6:S7^S16 (2003)
11. Guidelines for the Measurement of Radio Frequency Fields at Frequencies from 3 KHz to 300 GHz (GL-01), Industry Canada, http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf08512.html
12. *Occupational Exposure To Electromagnetic Fields At Radio Transmitter Sites*, T. G. Cooper, Health Protection Agency (Great Britain). Radiation Protection Division Health Protection Agency, 2007

13. U. C. Berkeley Non-Ionizing Radiation Safety Manual, 11/14/01, http://www.ehs.berkeley.edu/hs/64-laser-safety/111-non-ionizing-radiation-safety-manual.html
14. *Radio Frequency and Microwave Radiation Safety Handbook,* 2nd Edition, Ronald Kitchen. Oct 2, 2001
15. *Antenna Engineering Handbook*, 4th Edition, John L. Volakis, 2007
16. Antenna Theory.com, http://www.antenna-theory.com/

NEED EMF ASSISTANCE?

USAFSAM is always available to assist in any capacity.

Consultation Services – USAFSAM provides around-the-clock response and consultative capability for aeromedical, chemical, biological and radiological health hazard needs. The experienced staff advises health and medical officials on sample collection, epidemiologic surveillance, aeromedical treatment and hazard assessment. In every facet of aerospace medicine, from aviator health and hyperbaric medicine to advanced molecular detection and epidemiology, a USAFSAM expert is only a phone call away. We are available for site evaluations/assistance at minimal cost to the inquiring base.

Providing:

-AF health risk assessment education and training, consulting/analysis and research.

-Industrial Hygiene/Bioenvironmental Engineering

-Radiation Health (ionizing & non-ionizing)

-Dosimetry

-AFRAT

-Environmental Risk Assessment/Epidemiology

-Occupational Chemistry/Toxicology

The EMF Hotline is staffed and answered by the ESOH Service Center.

ESOH Service Center
DSN 798-3764
Com 937-938-3764
Toll Free 1-888-232-ESOH (3764)
Website: https://kx.afms.mil/esoh

USAFSAM Consulting E-mail: **esoh.service.center@wpafb.af.mil**